THE ROLLING OF STEEL.

Paper presented to the Institution, Sheffield Section, by H. Williams.

Introduction.

IN the year 1933 approximately 7,000,000 tons of steel were rolled in this country's ingot rolling mills. The products of these ingots passed into mills of many types for further rolling processes making numerous sizes of various shapes for engineers to fabricate into the framework of buildings, or for machining and shaping and treating for all forms of engineering construction. From simple beginnings engineers and designers have developed rolling mills into what are to-day equipments of great engineering capacity and ingenuity requiring driving equipment of many thousands of horsepower, and having auxiliary equipment of intricate design and construction. Specialists in the construction of such equipment and experts in its manipulation have become necessary and each section of this great development calls for its own individual study with its own peculiar problems and interests.

It is obviously impossible in one talk of this nature to make a comprehensive survey of such a field of industry. I have been informed that this is the first time the subject under examination has been presented to your meetings. In consequence I am taking the risk of presenting to you a lecture dealing with the subject in such a way that it may form an introduction, which will allow you to invite any specialist in any section of its activities to give you a lecture or lectures on his own particular interests. Endeavour will be made to submit facts and reasons for the same as simply as possible relative to the main principles of rolling. The application of some of these principles will follow and then lastly some illustrations of plant to amplify the previous notes will be shewn.

Descriptions and Sizes of Mills.

A mill will consist of at least two rolls mounted on their necks in bearings and driven through the wobblers or couplings shewn. A mill with only a top and bottom roll is named a "two-high mill." If three rolls are mounted in one stand as top, middle and bottom, it will be named a "three-high mill." If the working rolls of a two-high mill are each backed up by another roll for strengthening purposes it will be named a "four-high mill," and if each working roll is backed up by two more rolls the equipment is named a

October 1st, 1934 (Vol. XIV, No. 2, February, 1935).

" cluster mill." A mill using horizontal and vertical rolls at the same time on any particular pass is named a " universal mill."

Rolls, for plates, sheets, and strip are almost cylindrical. Rolls for blooms and shapes are cylinders into which grooves are cut or on which projections named collars are cast. The sizes of the mills in which the rolls are used are expressed in inches, most mills by the pitch centre of the pinions of the drive and plate mills also by the length of the roll body. A mill is also named according to its product, as for example, 36-in. blooming mill or a 12-in. bar mill. The size of a mill is determined not only by the finished size of its product but by the original size of material it is necessary to supply to it to make the product. As will be explained, rolls of a certain diameter are only able to receive and compress material of a certain range of sizes.

Deformation of Material.

Let us examine what happens when we roll a square bar between two cylinders without grooves. The object is to convert the square into a rectangular shape by reduction in its height. Deformation of the square is performed by compression and this produces a certain elongation. Usually there is also movement of the material at right angles to the direction of rolling, this action being termed " spreading."

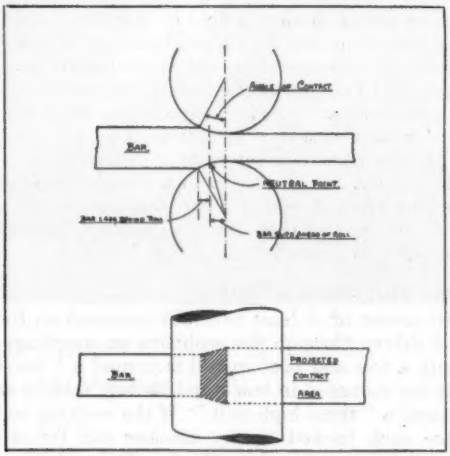


Fig. 1.

As will be seen from Fig. 1 the bar is reduced in height by the compression and its cross sectional area is less than before entering

the roll. The ratio of the areas before and after rolling is expressed in percentage and is known as " reduction."

Area of Contact.

The material enters the rolls due to the rolls biting it as result of the friction between the two surfaces. The extent of this is influenced by the angle of contact and the condition of the surfaces and the speed of rotation of the roll. An area of contact between the roll and the material is made and if we assume the top roll is transparent and we look down on this area it will appear in this instance as in Fig. 1.

A larger cross sectional area of material enters the rolls than leaves. The roll has a definite speed of rotation—consequently the bar leaves faster than it enters and at each point of contact, between the bar and the roll, a different speed of bar must exist. It is usual for the roll surface to be moving quicker than the incoming bar. Bar gains speed due to its reduction and a point is reached—named the " neutral point "—where the speeds coincide. From that point to the completion of reduction the bar continues to gain speed and becomes in advance of the roll surface speed. This effect is named " extrusion effect " or " forward slip." The constant roll surface speed meets a variable bar surface speed and wear of the roll surface results.

Spreading, reduction, and forward slip are affected by the following factors : (*a*) The quality of the material of the bar ; (*b*) the temperature on the surface and within the bar ; (*c*) the speed of rolling ; and (*d*) the friction between the bar and the roll surfaces.

Effect of Compression.

Deformation of the material arises from pressure exerted by the rolls and is influenced by several factors. The quality of material of the bar is of course necessarily an important one. The temperature of the material has an equally important influence. Trinks, in his book on Roll Pass Design, has shown the effect of temperature on what he describes as the " Resistance to Compression " of Iron and Steel. He determines a " Rate of Compression " as a ratio of :

$$\frac{\text{The velocity of compression/original thickness of bar.}}{\text{The velocity of compression is the Thickness reduction}}$$

$$\text{Time taken in reduction in seconds.}$$

As an example let us take a bloom of 10 inches reduced to eight inches in .08 seconds — 2 inches reduction in .08 seconds.

The rate of compression is :

$$\frac{\text{Velocity of compression}}{\text{Original thickness of bar}} = \frac{25}{10} = 2.5$$

He has based his values on tests conducted by himself and information of other investigators, and, while he claims these values may be subject to some modification as further tests are made, it is considered that they illustrate the effect of speed and reduction and temperature on the resistance to compression. The lower rates of compression are only found, in practice, in the early passes of blooming mills or similar equipment where speeds are comparatively low. At the higher rates of compression the curve flattens out. No definite reason has been submitted for this, but it is thought that the higher speeds of deformation increase the internal heat of the material and so soften it that the increase in stress is minimised. It will be readily realised how difficult it is to make calculations as to the forces in the working rolls.

Familiar contact with an actual rolling process shows how it is not possible to maintain any particular temperature throughout the whole process of the reduction of a bar, much less throughout any number of bars, despite the capable efforts of operators and their equpiment, and in consequence any deviation from the ideal can set up forces much different from those on which a designer had based his calculations.

Grooved Rolls and Friction.

A further important factor must now be examined. Hitherto for simplicity we have referred only to plain cylindrical rolls, but, to examine this factor we must consider those rolls whereon collars are cast or grooves are machined for the purpose of rolling material into shapes of various descriptions. This shape of section is a factor which has considerable bearing on the extent of the friction between the surfaces of the material and the roll. Not only do we have the friction arising from the effect of reduction, but we now have material in grooves in contact with collars at various diameters and additional friction arising from this contact. Any increase in friction increases the pressure per square inch of the area of contact. Plain cylindrical rolls in consequence will have smaller pressure for a similar reduction than rolls which are grooved for sections such as rails or joists or similar shapes.

Roll Spring.

When material is passed through the rolls stresses are set up by forces tending to spring the rolls apart. In hot rolling where the barrels of the rolls may be long relative to their diameter and the material being rolled is plastic, the tendency is for the roll to bend if it is held securely on its necks. In cold rolling where diameters are greater in proportion to the barrel length and where much greater pressures are experienced there is also a tendency for a flattening of the surface of contact, along with a reduced tendency for bending.

In the case of the bending of a roll we have a compressive stress on and toward the surface nearest the material, a tensile stress on and toward the outer and opposite surface, and some shearing stress on the centre line of the material being rolled.

It is possible to compute arithmetically or graphically approximately what this deflection is in a given case. By the same means it is possible to determine the approximate size of roll necessary to deform certain sizes and shapes of material, but in practice such calculations are liable to be affected by such influences as those of: (a) Variation in the properties of the roll material; (b) Casting stresses in or unsoundness of the roll material; (c) Stresses set up by the alternate heating and cooling of the rolls in the rolling process; (d) Cracks formed by this action forming sources of weakness; (e) Fatigue of the roll material due to widely varying loads; (f) Twisting stress or Torsion stress; (g) Variation in the quality and temperature of the material to be rolled.

A designer must endeavour to arrange and shape his passes to secure minimum ill effect from the adverse factors with which he is acquainted, and be guided by experience as to the factors of safety he requires in addition to these precautions. The bending or deflection of the roll mentioned is sometimes loosely referred to as spring, but this term really covers more than this movement. When pressure is brought on to the roll by the entry of the material being deformed, this pressure is transmitted from the roll necks to the bearings and their adjustments and then to the housings of the mill which may tend to move and stretch. This total movement is *that* "spring" which is of importance in the design of passes for the reduction of the product. In the rolling of plates and sheets this spring has considerable effect on the accuracy of the finish of the product.

In the rolling of sections finishing passes are usually placed at the ends of the roll barrels nearest the support of the bearings, where the minimum effect is felt. Care is taken in design to arrange reductions so that no pass has an undue proportion of spring as compared with another.

Friction.

As we have already noted, friction plays a large part in the rolling process. It is solely responsible for the ability of the rolls to cause the material to enter between them. The co-efficient of this friction is variable, being dependent on the roughness of the roll surface and the speed at which it moves. Some force is necessary to make the contact between the material and the rolls, and to overcome the repelling force. This is small when the angle of contact is small and the speed low, and increases with an increase in either item.

Wedge shaped passes have a greater friction force than passes between plain cylinders and consequently a larger contact angle may be used.

Values for the friction co-efficient cannot be given due to its variability, but Tafel, the German investigator, gives an indication of the relation of surface speed to gripping angle on rough and smooth rolls, showing in Fig. 2.

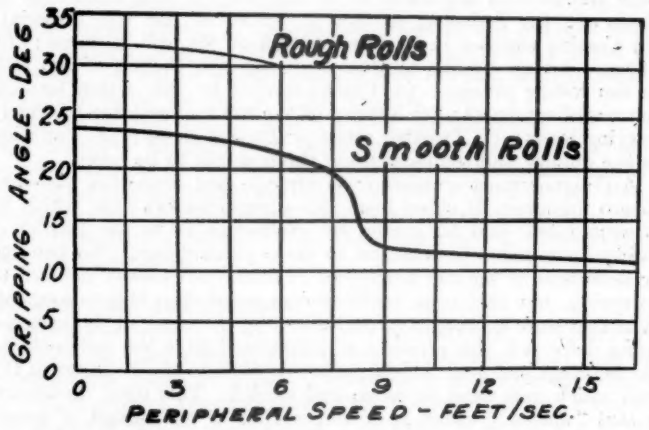


Fig. 2.

"Spreading."

Spread is affected by friction. Take the case of a rectangular bar in cylindrical rolls. In the case of a narrow bar in the process of deformation we have a narrow contact with the two rolls and consequently lateral friction is probably smaller than longitudinal friction, in which case spreading, in addition to elongation, will result. In a wide bar correspondingly greater lateral friction arises from the increased contact width and this friction may now be in excess of the longitudinal friction. Less spread and increased elongation will result. This is illustrated in Figure 3.

Spreading increases with reduction. Large rolls cause more spreading than small rolls when effecting similar elongations. It is claimed that spreading is constant at all temperatures under similar conditions of deformation. In the design of shaped passes spreading has to be carefully observed to prevent either under or over-filling of the section in any of the passes, and the influence of different shapes on this factor is a matter for careful study. In an

open pass of the type examined spread may vary from 20 per cent. to 40 per cent. on an ordinary billet shape under normal rolling conditions.

"Tension."

Friction plays a further part in creating by its presence, conditions which cause tension in the material being deformed. Figure 2 shows a piece of material between plain cylindrical rolls.

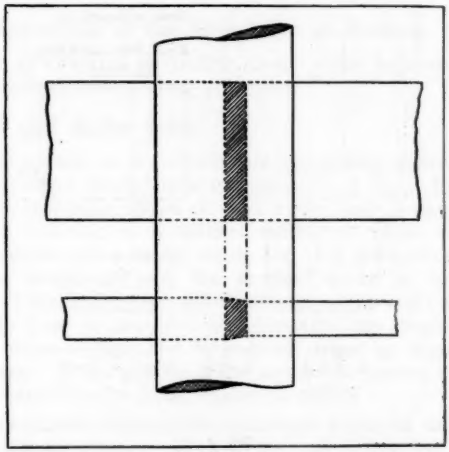


Fig. 3.

Between the point of first contact and the neutral point the bar is being pulled into the rolls by frictional force. Tension exists on the surfaces in contact with the rolls and compression exists toward the centre of the bar. This effect is greater when the angle of contact is greater, and the only ill effect on the material is that which may arise in cases of extremely heavy reduction and cause fine surface cracks. From the neutral point to the point of delivery, forward slip is being counteracted by the friction of the rolls on the surface layers of the material, but the inner layers are still subject to compression, and also have the extrusion effect urging them forward. The extent of this tension is small and no ill effect is observed.

From the point of delivery tension occurs from the surface of the bar being retained in contact with the roll surfaces by friction and tending to follow those surfaces instead of remaining straight as the centre of the bar. The stress set up is at 90 degrees to the direction of discharge and is usually very small in cases of passes without

grooves, but in cases where collars are in contact with the sides of the material the ends of the bar will sometimes open, part following each roll for a short distance.

Due to friction exerting its influence on the factors mentioned and the consequent result of roll wear, the roll designer must have full knowledge of its behaviour if he is to secure maximum maintenance of size and shape of his passes and maximum life of roll service.

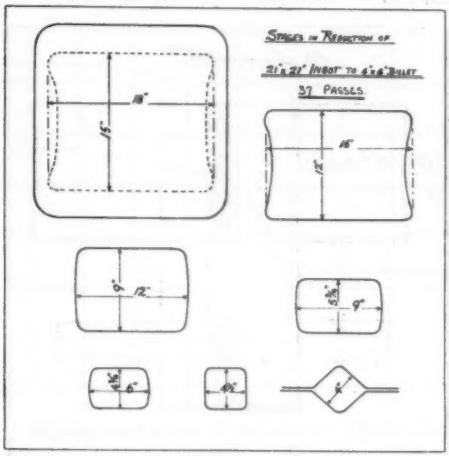


Fig. 4.

A few remarks on the arrangement of passes in grooved rolls will assist in appreciating the examination of the application of the principles already outlined.

Grooved Rolls.

Grooved rolls are so designed and turned that when set up a clearance exists between them which will allow for any expansion on heating. This clearance varies according to the sizes and types of rolls and conditions of service. Types of passes have various names according to their shape and location. Open and closed box. Diamond. Gothic. An open pass will be seen to be equally in each roll. The closed pass lies principally in one roll, three sides being enclosed by one roll and the other side being bounded by the other roll. Box pass is the term used for a rectangular pass with sides at 90 per cent. to the roll axes. Either pass mentioned may be termed so. If a square pass is set on its diagonal as shown it is termed a diamond pass. Diamond passes which have rounding in the corners or sides become gothics.

Slabbing action is that reduction which takes place on the top and bottom of material between plain cylindrical rolls. In grooved rolls reduction may take place at other angles than as in the purely slabbing action. As this reduction becomes nearer to the line of the axis of the rolls it becomes referred to as sidework and it becomes progressively less effective as it leaves the direct reduction of slabbing. The principles and effects which we have superficially examined apply to all rolling practice and cover all sizes and shapes of material.

Some Application of the Principles of Rolling.

Now let us examine particular items which represent the main types of product from rolling processes.

Blooming and Billet Mills.

The first process in practically all hot rolling of steel is that of reducing an ingot heated to a temperature of say 1,250° C. into a square or rectangular shape of such a size that it can be cut into lengths for utilising in a further rolling or other manipulating process. Ingots are usually made for this purpose in square or rectangular shapes to suit the product so as to secure similar reduction of dimensions in each direction. Material for subsequent rolling into bars or sections or frequently for forging is usually square in cross-section and is reduced from an ingot of almost square shape. If its size be 5 ins. square or over it is referred to as blooms and if below 5 ins. square as billets.

For blooms and billets three principal types of mill are used : (*a*) Two-high reversing ; (*b*) two-high reversing for blooms and followed by a "continuous mill" for billet production ; and (*c*) three-high mill.

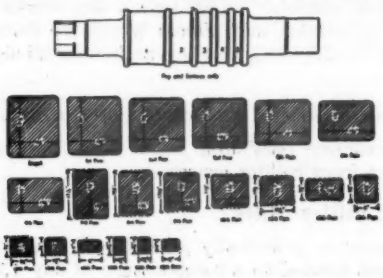
The rolls for blooming mills are of the simplest design and rely on slabbing action for the whole of their reduction of the material. The ingot being usually square or only slightly rectangular in shape is reduced in size in each direction in turn and maintains a rectangular or square shape down to its finished size.

The number and type of passes in such a roll are determined by the variety of size of product. For example, in a mill which has to produce a limited range of sizes the intermediate passes from the ingot are not necessarily of such shape and size that the material can be utilised direct from them. Rapid reduction to the sizes in chief demand is the principal object of the designer.

There are still, however, certain plants in the trade where numerous sizes have to be produced in the same roll from similar ingots. This prevents the most rapid reduction to a given size and the designer has to make the best of both requirements.

Fig. 5 shews an arrangement of passes and some reductions which are illustrating the requirements for rapid reduction on a two-high mill for rolling blooms.

All the passes are open box passes and to secure the shapes necessary the rolls have to be separated to various distances on each pass.



Design Showing Design of Rolls and Passes for Rolling from Ingot to 40" × 60" Bloom 40" Mill.

No. of Pass	No. of Groove	Aver. Dimensions Width in.	Aver. Dimensions Depth in.	Reduction Per cent.	Roll Speed r.p.m.	Est. Aver. H.P. Incl. Roll Neck Friction
1	1	19.0	19.9	5.5	40	2,140
2	1	19.3	18.4	6.09	40	2,340
3	1	19.0	17.1	8.45	40	3,500
4	1	19.3	15.4	8.62	40	2,810
5	1	19.6	13.6	10.1	60	5,450
6	1	19.8	11.9	11.6	60	5,410
7	2	12.3	17.2	10.2	60	4,600
8	2	12.5	15.2	10.4	60	3,770
9	2	12.5	13.5	11.0	80	5,180
10	2	12.7	11.5	13.6	80	7,220
11	2	12.4	9.85	16.5	80	11,000
12	2	12.7	7.5	22.0	100	13,400
13	3	8.06	9.72	17.7	100	11,200
14	3	8.40	7.12	23.7	100	11,000
15	3	7.75	6.00	22.3	120	11,700
16	3	8.15	3.94	31.0	120	11,200
17	5	4.20	6.84	10.6	120	4,090
18	5	4.32	5.72	13.9	140	4,730
19	4	6.10	3.97	2.02	140	2,240

Fig. 5.

The question may be asked why have not the various grooves been cut in the roll so as to obviate this lifting of the roll? Some of the reasons are: (*a*) Uniform and almost maximum roll cross sectional area is retained across the whole of the barrel; (*b*) the ability to separate the rolls and vary the effective pass area gives great flexibility in securing sizes; (*c*) the bottom roll passes are all

at similar height relative to the roller gear which moves the material to and from the rolls, and all sizes at every pass ride at about the same level.

Again it may be asked why, if the action of rolling the ingot is entirely that of "slabbing," is it necessary to have grooves in the rolls? It may be possible to roll without supporting collars on the rolls if the material would always retain a perfectly square shape.

This does not happen, however. One reason for this is that the spread of the material is not uniform in extent or shape during the whole of its reduction. In the early stages when the material is hottest and greatest in cross-section the spread is greatest at the surface of roll contact and a shape as shewn in Fig. 4 results.

As the temperature falls on the surface the spread is less, until a point is reached when the spread is greater in the bloom centre and a shape as shewn results. In the manipulation of the material its changing shape will thus affect its ability to ride truly on the roller gear and without collar support it would be pushed out of square and become difficult and perhaps impossible to reduce. Again all blooms do not deliver perfectly straight from the rolls and it would again be impracticable to control such recalcitrants without collars.

Some measure of support to the bloom corners is given by the collars, though this does not apply to every pass. It will be seen that in the speedy operation of a blooming mill collars are necessary for correct manipulation of the product. The roll shewn in Fig. 5 makes a minimum billet of approximately 6 ins. by 4 ins. which may be passed on to a further two high reversing mill for reduction to various sizes.

Continuous Billet Mill.

Rolls of similar design make the blooms necessary for passing forward to mills of the continuous type wherein rapid reduction of the bloom to the billet takes place down to the sizes of approximately 1½ ins. square in a series of 10 or 12 stands of rolls spaced at distances varying from 10 feet to 12 feet down to approximately six feet from each other. Each is a two-high stand of from 13½ ins. to 14½ ins. centres and with barrel length of say 15 ins to 18 ins. The passes are usually of the gothic or diamond type. The speeds of the rolls are so adjusted that as the cross section of the bar is reduced and consequent increased speed of bar results the revolutions per minute are increased progressively so as to prevent any possibility of buckling between passes. In the two-high reversing mills the material is turned through 90° periodically to secure correct reduction in all directions. This is necessary in "continuous" reduction and is achieved by special guides which are set up between stands and twist the billet in its progress.

Three-High Blooming Mill.

Fig. 6 shews a design from the book of Camp and Francis for a 42-in. three-high blooming mill. The passes here are not adjustable in the same sense as in a two-high mill. In the latter the free lifting of the rolls gives easy adjustment of every pass at any time. Once the three-high stand is set up for any ingot that ingot will pass along the grooves of what are in effect fixed-centre rolls.

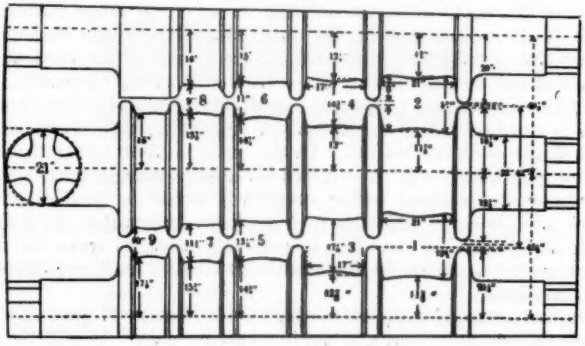


Fig. 6.

The adaptability of the two-high mill for rolling various ingot sizes into various bloom sizes is much restricted in the three-high and the number of sizes of bloom attainable is limited in any design. In order to secure a maximum number of passes on a given length of barrel it is necessary to make one pass over another and hence the groove in the middle roll must accommodate those in the top and bottom rolls in line with it. Consequently any difference in these passes can only be in depth and this is secured by making the groove in one of the outer rolls deeper than in the other. Customarily the roll diameters in the grooves decrease slightly from top to bottom so as to ensure that material in process tends to bear downwards on its delivery from the rolls.

As will be seen in Fig. 6 the drafts in this type of mill are heavy and in this design the heaviest are taken in the passes between the middle and bottom rolls. As a result higher stresses exist than in two-high blooming mills and wear on the bottom and sides of the grooves is more severe. Due to the inability to vary the draft in the various passes these mills are less suitable from the metallurgical aspect than the two-high mills.

To produce billets after the three-high blooming process it is customary to follow the rolls shewn with a further three-high stand or a continuous mill which can reduce the bloom of dimensions,

say 10 ins. × 9 ins. into sizes of from approximately 4 ins. × 4 ins. to 1½ ins. × 1½ ins.

For large outputs the latter is, of course most suitable but there are many works whose requirements can be met by the three-high equipment. Its pass lay-out may be of box-passes similar to those described for blooms but, of course, of such dimensions as are necessary for the production of billets. The further reduction of this material into smaller billets will be the subject of examination later in connection with the rolling of bars.

Slab Mill.

Material for subsequent rolling into plates is made from rectangular ingots and is reduced into rectangular shapes spoken of as slabs. Rolls with a large plain cylindrical portion of the barrel accompanied by one or two grooves for edge reduction are used for this material. The type of mill used for this purpose is usually a two-high reversing mill. After a number of passes on the plain part, edging is performed and followed alternately by work on the plain part as necessary to secure the required size and finish of material. The widths and number of the edging holes are determined by the conditions of any particular plant and its type of trade.

Rounds and Hexagons by Guide.

Let us follow the progress of a bloom or billet which goes forward into a mill for the production of a round or a hexagon.

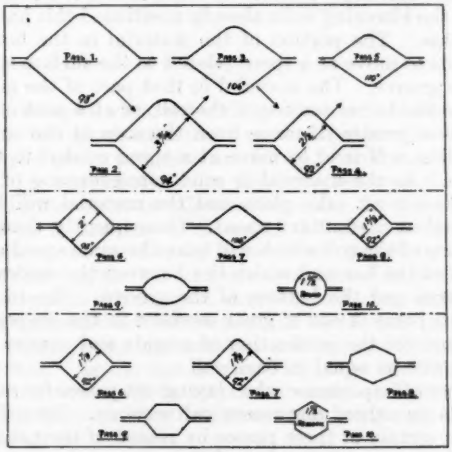


Fig. 7.

Fig. 7 shews a lay-out of passes for a round and for a hexagon. It will be seen that until the last two or three passes the shapes

are alike for each product, being either a diamond, a square, or a gothic. All these passes sit at an equal distance from their working rolls' axes and are cut equally into the previously plain barrels of the rolls.

Commencing with a square billet, entry is made on the diagonal into a diamond-shaped pass the width of which must be such that it is enough in excess of the diagonal of the square that any resultant spread will not cause the material to overfill the hole and flow between the barrel surfaces. Sometimes a combination of square and oval passes is used as an alternative layout.

The vertical dimension or height of the pass must be such that the incoming material makes an angle of contact that will allow the roll to grip the material. In the next pass the diamond now formed is turned through 90° and is reduced to a square.

For a round, having by this means secured a certain size of square billet, the next pass made is into an oval shape from which the bar is taken and placed with its long axis vertical into an almost round hole from which the finished bar is received. What are the features of these passes? The amount of reduction is determined by the angle of contact which is in turn affected by the roughness of the roll surface and the relative shapes of the incoming material and the pass in the rolls.

It is assumed that the incoming material will be of such a size that on reduction in its pass it will fill, or almost fill, that pass. In the case of the blooming mills already mentioned this has not always been the case. The portion of the material in the bottom of the groove tends to move at a speed related to the surface speed at that part of the groove. The material in that part of the groove which is nearer to the barrel surface of the roll, or at a part of the groove which is at a greater distance from the axis of the roll, e.g. at a greater radius, will tend to move at a speed related to that part of the groove. As the material is solid some slipping of some part of the surface must take place and the material will be delivered from the roll at a resultant speed. Consequently there is a point on one radius of the roll which will have the same speed as the speed of delivery of the bar and which lies between the centre line of the two rolls axes and the bottom of the groove. The importance of locating this point is not of great moment in the shapes illustrated as being used for the production of rounds and similar bars where the passes will be equal in each roll.

It becomes of importance when laying out passes for material such as channels or other unsymmetrical sections. Spreading is considerable in certain of these passes by reason of their shape and the heavy reductions, and shaping of the pass at the points where it cuts the surface of the roll is necessary to prevent overfilling giving rise to projections or fins on the bars. In all passes fillets are turned

on the rolls and in the last pass—the round—the hole is opened out as shewn in Fig. 8 to secure the best finish and prevent marking of the sides of the round or fins from overfilling.

The dimensions of the oval vary according to the views of designers, the quality of material being rolled, and the range of size of product. In entering the oval shape into the round pass it is essential that it should be in perfect alignment with the roll axes

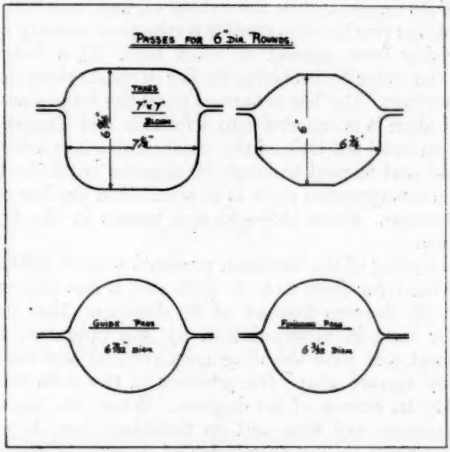


Fig. 8.

if it is to be reduced without twisting to one side or the other, and so disturbing the deformation that a round is not produced. For this purpose shaped plates or guides are set up to hold the incoming bar in position. A certain minimum clearance between the guide and the material must exist to allow movement. In the case of large rounds, say up to nine ins. in diameter, this clearance is very small in proportion to the total space between the guides and there is no fear of it permitting the bar to twist over even if it is almost round in shape. Hence in this range of sizes the ovals may be made almost circular and thus minimise the wear which takes place in the finishing hole as a result of the deformation and its resultant rubbing or frictional effect. As the size of round becomes less it is necessary to elongate the oval until in very small sizes, such as are found in wire rolling, it becomes very flat, sometimes being over twice as long on one axis as the other.

To secure the hexagon the similar progression of billet sizes is utilised and a hexagon "oval" is followed by the finishing roll. In some cases the billet size immediately preceding the oval is

shaped in preparation for the oval to form a "leader" into the hexagonal shape instead of being a square shape. Both rounds and hexagons are also rolled by hand.

Rounds and Hexagons by Hand.

In this case a square or gothic billet is held by tongs and entered into a round pass which has its sides opened up from approximately one third of its depth and to the extent of, say, one-sixteenth to the inch. The shape produced is similar to the pass namely a round with a bulge arising from spread on each side. This bulge shows its position to the roller by its being darker in shade than the remainder of the bar surface. The bar is turned until the bulges are on top and bottom and then it is entered into a further and similar pass of less size and so on until the hole of the finished size is reached. Here the bar is passed and turned through 90 degrees until the bulge which comes at the unsupported sides is so small that the bar is round in a commercial sense. From three to five passes in the finishing hole should suffice.

The hand rolling of the hexagon presents a more difficult problem in the carrying over from hole to hole and it has also to be turned up through 60 degrees instead of 90 degrees. This increases the necessity for care in manipulation by the operator. Squares are rolled by hand and with the diagonals vertical and horizontal. To secure a true square shape the grooves in the rolls must have an angle slightly in excess of 90 degrees. When the square is being rolled the corners cool first and on finishing they do not contract to the same extent as the remainder of the shape which, in consequence, becomes truly square.

Angles.

After this brief survey of the solid shapes examples of sectional material should be examined. An angle presents typical examples of effects which the designer and roller have to observe. Figure 9 shows the lay-out of passes for the production of an unequal angle.

Here we have a section which is not symmetrical. One side is larger than the other and yet it has to be placed in the rolls so that reduction may take place in such a way as to permit delivery from the roll to be straight and free from twisting. Let us assume that the drafting was so ill-arranged that one leg was elongated much more quickly than the other. As the two legs cannot separate, the one being rapidly reduced will pull the other along with it, and as the material necessary to allow this elongation has to be found the effect will be that the pulled leg will shorten. Again it is found that the position shown is that which produces least end thrust on the collars of the rolls. The tips of the angle legs should come at the roll parting and so have approximately the same speed. This tends

to give the maximum amount of slabbing action which is of course the most direct form of reduction.

As can be realised, any tilting of the angle from this position increases side work and inherent thrust, and in the extreme and improbable case of an angle with one leg set horixontally and one vertically we should have maximum sidework on the vertical leg making reduction exceedingly difficult. Also the effect of difference

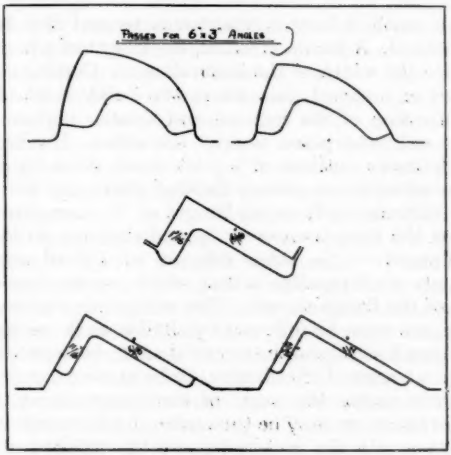


Fig. 9.

in diameter and relative speeds at the various points of contact on the section would be accentuated. It will be noticed that the designer really forms his angle in three passes, the following passes being of angle shape varying in thickness only. The third holes in this design is the most important one and in it the grooved billet becomes of angle shape. The longer leg offers proportionately greater resistance to displacement and deformation than the shorter leg, giving rise to the tendency of the rolls to give to the shorter leg side, and if not counteracted this may produce an increased thickness of the longer leg. This is prevented by proportioning the thicknesses in this pass so that the short leg has a similar displacement effect to the other. It is customary to place angles with approximately 60 per cent. of the section below the pitch line for best delivery and reduction results.

Joists.

The beam or joist is the most important sectional shape in structural work and presents considerable difficulty in rolling and design.

Its long flanges and thin web limit the methods which may be adopted in its production as well as the method usually adopted in this country. Other methods are used, the principal ones being the diagional method where the web is tilted alternately left and right to give increased slabbing action on the flanges, and the Universal Mill or "Grey" method with horizontal and vertical rolls which permit of varied flange thicknesses without variation of the web.

The usual method here is sometimes termed the flat or beam roughing method. A bloom is taken, the height of which is approximately twice the width of the beam flanges. Cutting in of grooves is performed in a closed pass where the bulky sides of the shape prevent elongation of the reduced and smaller portion and consequent flow will take place toward the sides. Having created a shape which shows outlines of a joist, work must be done on the flanges to produce the necessary finished shape and sizes. It is not possible to work similarly on all flanges at the same time and while side work on the flanges on one side and slabbing on the web take place the flanges on the other side are in a dead or closed hole where the only work possible is that which can be done by pressure on the end of the flange therein. The work done on one side of the joist in one pass must be followed by similar work on the other side in the next pass if strains in the material are to be kept at a minimum and consequent control of reduction to be attained.

In the early passes the angle of the flanges is at its greatest, and heavier reductions may be thus taken by the possibility of some slabbing action. As the material nears the finished shape and is losing heat the flanges are also sloping to a less degree and the care necessary in using side work is equally necessary because of loss of plasticity. Care must also be taken in the later passes to have similar reduction on flange and web with slightly more on the former. To secure work on opposite flanges of the joist it is necessary to either turn the material over on alternate passes or to arrange the pass design so as to make the live pass alternately in the top and bottom rolls. This latter method must be adopted on all but very light sections which permit of easy manipulation.

The shapes of the passes must be such that the amount of material being carried from a live hole must fill the dead hole after some upsetting work has been done on the flange tip. This calls for correct arrangement with full regard to the effects of effective radius and friction at the various radii of the contact surfaces. The tapered shape of the joist flange facilitates entry of material and also assists in its delivery, but it is necessary to lubricate the grooves freely to assist the auxiliary equipment of stripping guards to overcome the tendency of the material to adhere to the roll surface. The tapered flange, in addition, is essential to secure means of

dressing the roll to correct the shape after wear has taken place after rolling. Rolling in the continuous mill by the "Grey" method permits the production of joists with flanges free from taper and of greater length in comparison with the web length than in the process illustrated and it is utilised for special work such as is required for bridges.

The sections mentioned are only two of many which call for great skill in design but which are produced by observation of the principles briefly reviewed. Considerable experience must necessarily be acquired to combine with the theoretical information available ere a designer can successfully lay out known passes in a new equipment, or those of a new section in his existing equipment, and produce bars correct to size and shape and with minimum loading of his source of motive power and with roll wear reduced to the lowest degree. In all items dealt with, correct manipulation and control of the material in process is effected with the assistance of auxiliary equipment set up at either side of the rolls. This equipment ensures that incoming material is entered into the passes in the position intended by the designer and consists of cast iron or steel or forged steel plates termed guides, arranged on a beam or cramp bar. A similar set of plates with, in the case of flanged sections, specially forged shapes which enter the grooves assist in correct delivery of the material from the pass and prevent any tendency of the bars adhereing to and following the roll surface.

When performing this function the plates are usually referred to as guards. Hence, on a reversing mill they become guards and guides alternatively. It is endeavoured so to arrange the passes that there is a tendency in most types of work for the material to deliver downward on to the guard equipment where this can be more solidly set up without destroying the operators visibility of the process. In the case of special guards which fit into the grooves of the rolls it is usually necessary for these to be set up both over and under the pass to strip the flange, which, due to its greater area of surface contact at varying radii, often tends to hold tightly to the roll.

Plates and Sheets.

Let us leave this brief survey of the rolling of shapes for what appears to be a very straightforward operation—the rolling of plate or sheet. Plates of many tons in weight down to sheets of but a few pounds are all reduced from the ingot to an intermediate rectangular cross section and passed through one or more heating processes before being finished between rolls of plain cylindrical form or which have been given a small sweep either convex or concave according to the particular production circumstances. Plates are usually rolled from slabs of some twelve to twenty times

their thickness which have been reduced by passing to and fro between the cylinders aforementioned until the edge measures the required amount. Now measure the thickness across the end of the plate and it will be found that at the centre the thickness is greater than at the side. Here is an undesirable condition which has only been improved upon but never removed in the years during which rolling has been taking place. The wider the plate in any one pair of rolls the greater is the variation.

Refer back to Figure 3 where it is shown that in a wide strip spread is resisted by friction between the material and the roll surfaces, whereas in the narrow strip spread takes place to a greater extent. A plate is a " wider " strip and one with a very short length of area of contact as compared with its width. The desire for spread is the same along the whole width but only the outer edges can satisfy that desire. The ability to spread is reduced as the centre is approached. The forces tending to elongate are equal along the whole of the width of the area of contact. Consequently, there is a tendency for a building up of material where it cannot be spread and on its release from the rolls it is found that the plate thickness is greater in the centre than at the edges.

In a mill where the diameter of the rolls is small there appears to be a greater tendency for this difference than where the rolls of similar length have greater diameter. This is generally explained by the assumed springing or bending of the roll. It is none the less the fact that with rolls of very short length where it would appear unlikely that bending can take place when material is being reduced by the whole length of the barrel this variation in thickness is present to some degree. Where uniform temperature conditions and parallel roll surfaces exist it is generally the case that in any one pass, after a plate or sheet has left the slab stage of reduction, the front end is thicker than the later portions and that at the last end to leave the roll the plate or sheet is thinner than in the remainder.

One writer explains this as follows : " When the first end of the plate or sheet enters the rolls the flow of the steel to produce elongation is opposed by every molecule composing the steel from the first end to the last end of the sheet and the metal starts to build up in front of the rolls until the inertia of the molecules is overcome and they are forced into motion. Then the flow starts and the resistance gradually falls off until near the last end of the sheet the resistance has fallen off so much that the reduction of the sheet in thickness is considerably greater and an increasing lightness in gauge will result to the end. This difference will be greater with a larger diameter roll as the smaller roll will permit the flow to commence sooner and the flow will be easier."

Variation in heating and concavity of the rolls arising from wear so affect this condition that in the hot rolling of plates and heavy

sheets the back end of the material is frequently slightly thicker than the front. Further variation can take place from heating up of the rolls increasing their diameter in the centre and tending to cause convexity and produce a plate thicker on the edges than at the centre. Again if the rolls are not in true vertical alignment other variations will result.

Two-high reversing mills and three-high mills are the usual type used for plate production but a few mills with horizontal and vertical rolls—universal mills—are in service. The three-high mill is usually of the type designed by Lauth. It has top and bottom rolls driven and a free middle roll of approximately two-thirds of the diameter of the others which lifts and lowers so that the plate is rolled between either the top or bottom roll and the middle roll backed by the other roll. The effect of this reduction between rolls with different areas of contact is that the smaller roll supported on its entire length by the larger roll cuts deeper into the surface than the larger one on the other side of the plate. The length of its contact area relative to the width of it is very small, and we have seen that this combination usually accompanies increased elongation and reduced spread. We now have increased reduction and elongation and reduced spread resulting in less variation from side to centre of the plate. This fact has been made use of in the modern four-high mill where two small rolls are backed by two large diameter rolls and variation in thickness is considerably reduced over the results in mills where the larger rolls are in contact with the material.

Sheets.

The principles applying to plate rolling are equally applicable to sheet rolling. Other factors as apart from roll wear arising from the friction set up as previously described affect the production of the thinner sizes of plates and sheets. Temperature plays its part more than in plate rolling. Plates are usually rolled in mills where water is used to maintain coolness of the rolls. This is not practicable in sheet rolling where hand operation is the rule and the material would be cooled off by the water which would also interfere with the operators' manipulation of his product.

The temperature, as previously stated, affects the contour of the roll and to counteract its effects concavity to meet the circumstances prevailing in any case is turned in the rolls. The material rolled is graded to meet the requirements of roll wear and expansion at the different parts of its service period. Heating up of the "Swept" rolls by one of the various means available is also necessary prior to the production of material to give the correct contour. Sheets of various gauges down to 0.01 have to be secured by hot rolling in packs of from two to eight thicknesses with tolerances of only two or three thousandths. This calls for great accuracy in the turning

or grinding of the rolls and specialised skill on the part of the operator and his supervisors in securing and maintaining the correct roll conditions to produce the product within these tolerances and also possessed of the necessary finish of surface so much in demand to-day by the users of sheets. Sheets are usually produced in two-high mills, but three, and four-high equipments are being adopted for thicknesses of, say, from 0.06 in. upwards.

Cold Rolling.

Cold rolling of strips or sheets is practised to secure improved surface finish, less thickness than is possible by hot rolling, even less variation in thickness or a change in the physical properties or, lastly, a combination of two or more of the items mentioned. Some special cold rolling of shapes is done but the quantity is slight as compared with the strip and sheet materials so processed. The extent of the reduction is determined by the results it is desired to attain and by the black or hot-rolled strip or sheet available as the raw material.

The actual method of reduction is similar to that of the hot material except that roll pressures are much greater and the equipment has to be designed to meet this contingency. Narrow strip is usually reduced in two-high stands by passing to and fro as in hot plate or sheet rolling, but, due to its length, it is coiled on drums on each side of the mill. The rolls are driven and tension is maintained on the strip on both ingoing and outgoing sides thus assisting in its reduction. One special mill relies on the coiling drums to draw the material through the rolls, these latter being non-driven. Later equipment utilising the four-high principle with its small diameter working rolls and the large backing rolls has by so bringing into service the already noted advantages greatly increased the rate of production. This type of equipment has increased the widths which may be effectively rolled since it reduces the variation between centre and side. Heating up of the working rolls—an ever present trouble in cold rolling—is reduced by the lesser frictional effect.

Heavier drafts due to the smaller rolls are also possible. This equipment is not generally adopted for strip of less than 15 in. wide, below which width excellent results are attained by the ordinary two-high equipment. There appears to be no general practice, however, in the method adopted. For similar sizes it is possible to find : (a) Single stands with rolls two or four high or in cluster and idle or driven. (b) Equipment as in (a) with tension applications varied. (c) Tandem or continuous stands with variation of tension application.

All these equipments have a common problem which greatly influences their effectiveness—namely, temperature rise due to

friction arising from the process. Variation in the contour of the roll barrel and heating of the bearings under high pressure are points of serious consequence. Correct lubrication and cooling of the necks and barrels of the rolls plays an important part in the efficiency of the operations.

Conclusion.

In the short time at our disposal it has only been possible to comment briefly on the main principles of rolling practice in certain of its applications. Each section of production practice referred to provides in itself a field of experience and knowledge for many lectures of this duration, and there are other sections of practice which have received no attention to-night. It is hoped, therefore, that enough interest has been stimulated for your members to inquire further from other sources for more information and enlightenment. Thanks are due to my employers The Park Gate Iron & Steel Co. Ltd., and in particular to Mr. Fred Clements the General Manager, for the facilities provided which have enabled me to prepare this paper and its accompanying slides. To those gentlemen who have assisted me in various ways in the preparation of these notes I offer my appreciation.

RECENT DEVELOPMENTS IN WORM GEAR MANUFACTURE.

Paper presented to the Institution, London and Southern Sections, by H. Walker, B.Sc., A.M.I.A.E.

THE greatest change that has taken place within recent years in connection with worm gearing is the adoption of high lead angles, and close ratios. At one time worm gearing was only considered suitable for use where large reduction ratios of between 10 : 1 and 60 : 1 were required. It is true that worm gearing still holds the field when these large ratios are under consideration, but in addition it is being increasingly realized that modern worm gears are also suitable for ratios more nearly approaching 1 : 1. It is in fact no exaggeration to say that worm gears show their greatest advantage on close ratios approaching unity because it is with these ratios that they give their highest efficiency and biggest load capacity.

Close Ratio Worm Drives.

It may thus be stated that whereas formerly worm gears were used out of necessity because other types of gear reduction could not give large ratios in a compact space, nowadays worm gears are also used from choice on close ratios because they have advantages over other types of gear drive.

The use of worm gears for motor car and commercial vehicle drives has probably helped to bring out the advantages of the close ratio high efficiency drive. Automobile worm gears have ratios usually lying between 4 : 1 and 8 : 1, but ratios less than 4 : 1 and more closely approaching 1 : 1 are now quite common in the case of machine tool and other industrial worm drives.

Close ratios usually imply that the worm wheel runs at fairly high speed. The magnitude of the noise produced by a pair of worm gears is dependent on the speed of the worm wheel more than on the speed of the worm, and consequently the accuracy required on close ratio gears is of a high order. In addition the high lead angle of such gears complicates manufacture. The radially relieved hob was the only type used in the past. After sharpening, such a hob is reduced slightly in diameter.

Theoretically, however, no change in diameter of hobs permissible because it should always be of the same diameter as the worm

London, November 2nd : Southampton, November 21st, 1934.
Illustrations by courtesy of "Machinery."

if a correct wheel is to be produced. This variation from theoretical accuracy does not make much practical difference on a low lead angle gear, but on the modern high lead angle gears it is sufficient to introduce noise and inaccuracies which are seriously detrimental to present-day requirements.

The purpose of the present paper is to show how, by utilizing certain recent developments in worm gear manufacture, a combination of old and new processes can be obtained which forms a sound basis for the manufacture of accurate worm gears.

Worm Thread Grinding.

The essentials of a worm thread grinding machine are: (a) To grind the profiles of the worm threads to the correct lead and spacing; (b) to obtain accurately a predetermined shape of profile on the thread, so that it will correctly mesh with the worm wheel teeth, and (c) to obtain a smoothly-finished thread profile.

Worm-thread grinding machines invariably consist of an arrangement for traversing the worm past a fixed grinding head, the axial movement of the worm being synchronized with a rotary movement, and the relative speeds of axial traverse and rotational movement being adjusted to give the required lead of worm thread. For multiple thread worms, an arrangement is usually provided whereby, after one pass of the worm over the abrasive wheel, the worm is automatically divided to the next thread during the return traverse so that the grinding is continuous and automatic. In these respects, worm-thread grinders of different makes do not appreciably differ in principle, and it is in fact difficult to conceive any other mechanical and practicable plan which would give the same results. At any rate, the scheme satisfactorily fulfils the requirement (a) above. With regard to requirement (b), the question of ensuring a correct profile shape on the worm thread has created a difficulty which has only recently been satisfactorily overcome.

The Requirements of Worm Grinding.

It is essential, on a worm-thread grinder, that some arrangement is available whereby the operator can true the grinding wheel and set the machine to produce accurately the required shape of thread, and also reproduce this thread shape with facility on any future occasion.

This requirement will be made clear by considering the analogous case of spur gear tooth grinding. On all spur gear grinders there is a definite arrangement for mechanically producing the required shape of tooth. On the Maag grinder, for example, an accurate involute shape is obtained by tilting the grinding wheel, which is of saucer shape and grinds on the side only, at the pressure angle of the gear; this gives the effect of generating the shape by means of a straight-

sided rack tooth. The principle of the Lees-Bradner machine is somewhat similar except that the grinding wheel is large enough to cover the full tooth face of the spur gear without the necessity of traversing across the tooth width. There is also the formed wheel process in which the grinding wheel is trued, by means of a diamond following a former, to the correct involute shape. In the case of worm-thread grinding, there has in the past been no satisfactory equivalent to the spur gear methods, and the accuracy of the profile shape has been dependent to a great extent on the skill of the operator.

The most recent development in worm-thread grinding practice has, however, overcome this difficulty and it is now possible to ensure accuracy of profile shape in conjunction with convenience of operation. This development is based on the employment of a different form of grinding wheel and a different method of presenting the wheel to the worm thread.

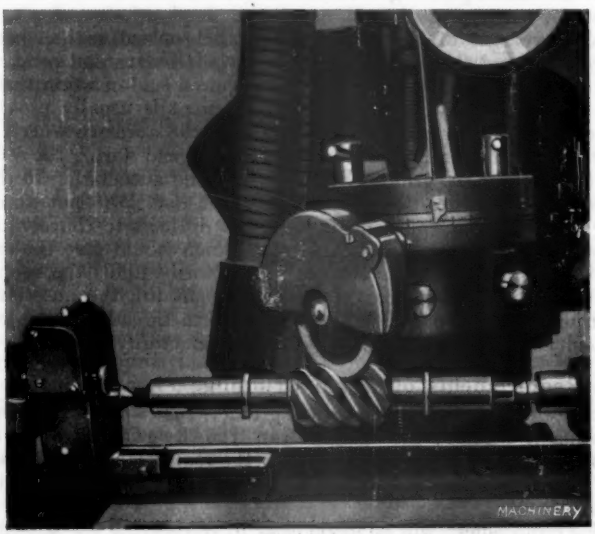


Fig. 1.

The Disc Wheel Method of Worm Grinding.

In previous grinding machines the practice has been to use a disc type of wheel, grinding on the face of the wheel. Fig. 1 clearly illustrates this method of grinding. The contact of the grinding

wheel with the worm thread is shown in Fig. 2. It will be seen that the axis of the wheel is swivelled to lie normal to the thread. The difficulty with this arrangement lies in the fact that if the abrasive wheel is trued to a particular shape (say a straight line or any predetermined curve) the profile of the worm ground by the wheel does not correspond to the shape of the abrasive wheel, owing to a particular kind of interference which takes place in milling or grind-

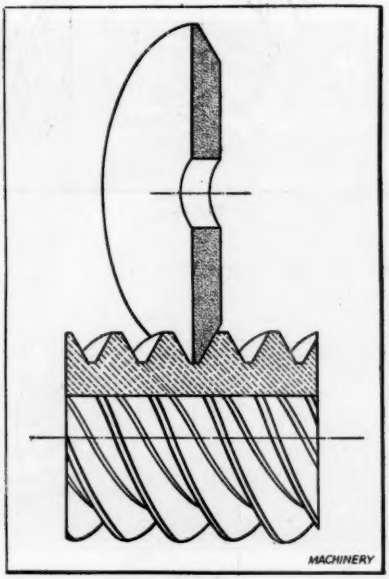


Fig. 2.

ing worms. The magnitude of this interference or deviation in shape varies with the diameter of the grinding wheel, and unless the wheel can be kept to a constant diameter, the operator has little control over the shape produced.

Another method of using a disc type of abrasive wheel is shown in Fig. 3. In this case a flat-sided wheel is employed. This flat-sided wheel can, of course, be trued by a diamond moving in a straight line, and, if its axis is turned to a predetermined angle in relation to the worm, the flat plane represented by the side of the wheel will generate on the worm thread an involute shape on the cross section of the worm. In this method the shape produced is, within practicable limits, unaffected by the diameter of the grinding wheel. There is, however, only one shape of thread which can be produced

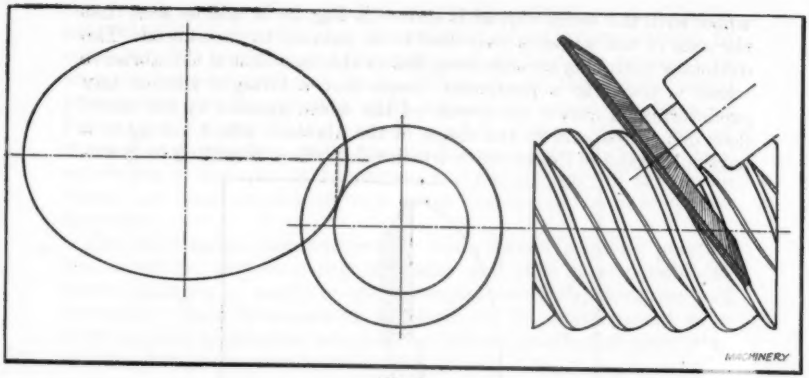


Fig. 3.

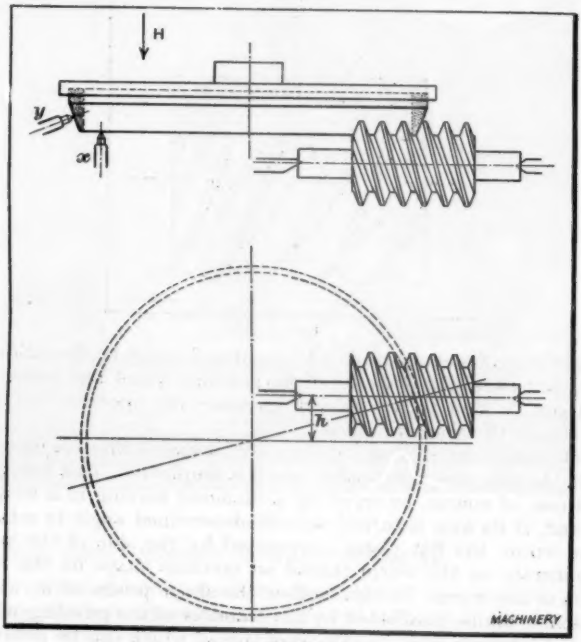


Fig. 4.

by the method in question, that is, the involute shape. Moreover, the angular settings of the grinding head are complicated and it is seldom that the required shape can be produced and reproduced without trial and error.

In the latest process the disc type of wheel is dispensed with. Fig. 4 shows the form of abrasive wheel employed, and Fig. 5 further illustrates the principle involved. It will be seen that the grinding

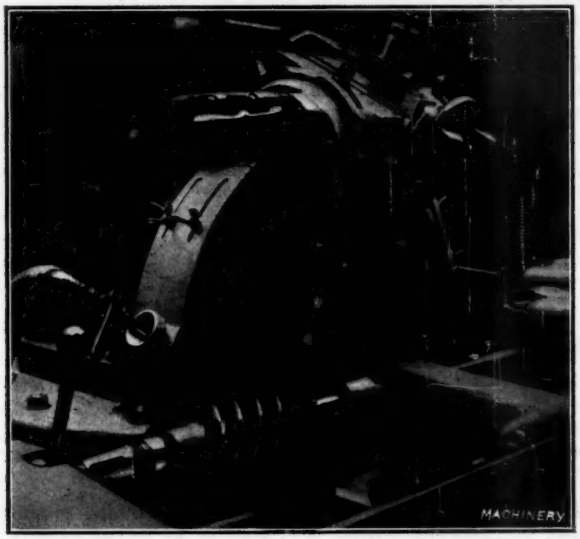


Fig. 5.

wheel is of large diameter and annular form. It grinds on the outside periphery which is in contact with one side of the worm thread. The rotating worm is traversed past the grinding wheel in the usual manner of a thread grinder.

Referring to Fig. 4, the centre of the grinding wheel is set at a height h above the axis of the worm, this height being variable, according to the lead angle of the worm to be ground. No great accuracy of setting is required as the object of this offset is merely to bring the wheel into such a position that it grinds on its external periphery, without any interference taking place between the inner surface of the wheel and the adjacent thread.

The Advantages of the Annular Wheel.

One advantage of using this type of grinding wheel is that its

effective diameter remains unchanged after truing has taken place, hence the shape of thread produced is always the same. In Fig. 4 the two diamonds x and y which are used for truing the tip and the outside of the wheel respectively, are fixed to slides rigidly attached to the grinding head. The diamond x always moves in a straight line.

The diamond y is guided with the aid of a former to produce the required shape of profile. The wheel is trued by first moving it forward along its axis (in the direction H) for a short distance. Then the diamonds, which have not moved, are traversed over the wheel. It will, therefore, be seen that the effective diameter and the shape of the wheel are unaltered. Provision is made on the truing device, which is shown in Fig. 6, for setting the former always in the same position and for setting the diamond x in a definite plane

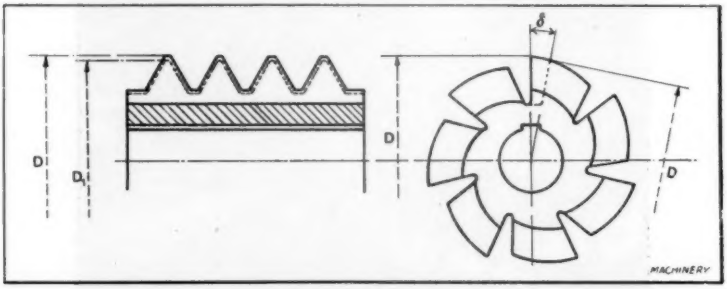


Fig 6.

in relation to the worm axis. Thus if the machine settings are changed for different worms, it is possible to repeat exactly, and without trial and error, any worm previously ground.

It will be observed that in this method of grinding the wheel makes contact with the worm on its outer periphery, that is to say, the grinding process is equivalent to cylindrical grinding. On machines previously used, the disc-type grinding wheel made contact on the side, which is in the nature of face grinding. This difference creates a corresponding difference in the production times and in the resulting surface finish of the worm thread.

On a disc type of grinding machine the process is slow, because the wheel does not cut cleanly, and if anything more than a light cut is applied, there is a danger of burn and surface cracks appearing on the worm thread. The diameters of the spindle bearings are usually restricted in size, and the wheel is often lifted or deflected off the work without taking a clean cut. On the other hand, in the case of a wheel grinding on its outer periphery, the cut is taken

cleanly. In this case the spindle bearings are not restricted in size and a powerful drive can be arranged to the grinding wheel. It has been found possible in practice to remove 0.010-in. from the side of the worm thread at one pass of the grinding wheel. As this is more than the amount usually left on a worm thread for grinding allowance, it will be obvious that only one roughing cut and one finishing cut are necessary over each side of the threads of a worm to finish it completely. The speed of traverse of the abrasive wheel along a worm thread on this machine is about 60 inches per minute for any pitch, and this will give some idea of the very short time necessary for completely finishing a worm. The return stroke, during which dividing takes place, is rapid. Another point which makes for rigidity in the wheel and clean cutting is the fact that there is a steel backing plate which cannot deflect by any appreciable amount.

Owing to the comparatively large diameter of wheel used, the cutting surface of the wheel retains its shape after truing longer than does a disc wheel, and does not become clogged up so quickly. Moreover, the operation of truing the wheel is so simple and occupies such a short period of time that the operator has no excuse for not keeping the wheel in good condition.

The Elimination of Polishing.

It has been usual in the past to polish worm threads after the grinding operation. The face grinding action of the disc wheel leaves grinding lines diagonally across the thread surface, and if these are not polished out they tend to set up a cutting action, similar to a file, on the worm-wheel teeth. Unfortunately, these marks may be so deep that in removing them by polishing, the accuracy of profile and lead of the worm are impaired, with detrimental results to the gears.

On the new type of worm-thread grinder described, owing to the cylindrical grinding action of the wheel and its accurate truing device, the tooth finish approaches that which is obtained on a cylindrically-ground shaft. Consequently, no after polishing is necessary. After a short period of running with the worm wheel under load, the thread surface becomes polished and smooth with no trace of grinding marks.

The cutting of the worm-wheel teeth is just as important as the grinding of the worm threads, but the difficulties met with lie not so much in the construction of the hobbing machine as in the manufacture and design of the hob for cutting the teeth. Worm-wheel hobbing machines are to-day all very much alike in basic principle. They consist essentially of a table for supporting the work and a spindle at right angles to the table axis for supporting the hob, the relative speeds of table and hob being variable to accommodate

different ratios and sizes of work. A tangential feed is provided whereby the hob can be fed along the direction of its axis into the worm wheel.

Machines built generally on these lines fulfil satisfactorily all that is required of a worm-wheel hobbing machine, provided they possess the necessary rigidity to give ample support without deflection to the hob and the worm wheel, and provided they are accurate, the accuracy depending largely on the gear (usually a worm gear) which drives the table. Various refinements can, of course, be embodied in these machines.

The fact remains that the biggest source of inaccuracy in worm-wheel hobbing lines in the probable inaccuracies of the hob, since the hob controls the shape and angle of tooth produced on the worm wheel. While errors traceable to the machine itself can usually be kept within fine limits, considerable difficulty has been found to centre round the production of an accurate hob, particularly in these days when multi-start worms of high lead angle are being increasingly used.

The Characteristics of the Ideal Hob.

The ideal worm-wheel hob may be defined as a cutter, the envelopes of the active cutting edges of which are the same as the thread surfaces of the corresponding worm (except for modification to the thickness of the tooth and the top of the tooth to give backlash and running clearance in the worm wheel). This definition of an ideal hob is not so easy to fulfil in practice as appears at first sight. The early types of worm-wheel hob consisted of a cutter made exactly like the worm, gashed at right angles to the thread to provide cutting edges, and with the teeth relieved radially to give cutting clearances. Such a hob fulfils the definition of our ideal hob, but immediately the hob is sharpened it fails to fulfil the definition. Fig. 6 shows the effect of sharpening. A small amount of metal is removed from the fronts of the gashes in sharpening, and owing to the radial relief, this sharpening naturally reduces the effective diameter of the hob, bringing the effective cutting profiles of the teeth nearer to the axis of the hob.

It follows, therefore, that after sharpening has taken place, a hob of this type is no longer theoretically correct, and repeated sharpening makes its form depart more and more from that of the worm. After a hob of this type has been sharpened, it is necessary to bring the hob axis closer to the worm-wheel axis during cutting.

Inaccuracies Resulting from Reduced Hob Diameter.

The effect of using this small diameter hob is two-fold : (1) Since the lead angle of a hob or worm of constant lead varies according to the diameter on which the angle is measured, it follows that the

sharpened hob will have a different lead angle to the original hob before sharpening. The effect of this on the worm wheel is to give an incorrect spiral angle on the worm-wheel teeth. (2) The formation of the worm-wheel teeth in cross section will be of incorrect radius. This effect is shown in Fig. 7. Since the hob operates at a different centre from the worm there will be a difference in the tooth curvature. A point such as P on the worm will meet the side of the wheel face

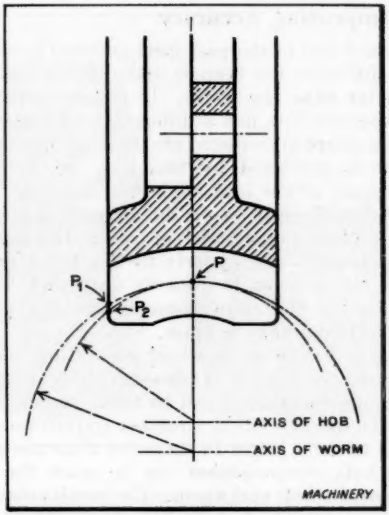


Fig. 7.

at P_1, whereas a corresponding point P on the hob meets the wheel face at P_2, and consequently the hob will leave extra metal at the sides of the wheel face which will interfere with the worm.

The combined effect of these two errors is that instead of the worm making contact fully across the face of the wheel tooth, the contact lies only on one or on both corners. This departure from theoretical accuracy causes noisy running of the gears and high specific tooth pressures, due to the fact that the load is not distributed fully across the wheel face. It may also lead to accelerated wear of the wheel tooth and the possibility of pitting. A gear so cut will not rectify itself by running in, and will in most cases remain noisy throughout its entire life.

In practice, the results of errors introduced by repeated sharpening of the hob are less pronounced on single-thread worms or worms of low lead angle than on multi-thread worms of high lead angle.

Single-thread worms usually indicate that the worm wheel revolves at a comparatively slow speed, and small errors of this nature will not cause excessive noise. The modern tendency in high-efficiency worm gearing, however, is to employ multi-thread worms of high lead angle, and in this case the theoretical inaccuracies introduced by using a hob of this type are sufficient to impair to a very pronounced degree the silent running of the gears.

Methods of Improving Accuracy.

A method which has in the past been adopted in an endeavour to overcome this difficulty has been to make the hob initially larger in effective diameter than the worm. It will be apparent, however, that a large-diameter hob has a different lead angle to the worm, and therefore the gears so produced are theoretically incorrect. Here again, the errors produced by this hob are not very noticeable on worm gears of low lead angle, but on high angle gears are very pronounced in their effect on the amount of noise produced by the gears. As the hob is sharpened, of course, the diameter becomes smaller and approaches more nearly to the diameter of the worm, so that the results continue to improve until such time as the hob is sharpened down to the same diameter as the worm, after which the results begin to deteriorate again.

If the hob axis on the worm-wheel generating machine, instead of being permanently fixed in a plane at right angles to the work mandrel, is arranged so that it can be tilted through a small angle, then this may be used to effect a further improvement when using a hob which is initially larger in diameter than the worm, because by tilting the hob, compensation can be made for the difference in angle between the hob and worm. The results obtained by using this swivelling movement show an improvement over those when the hob is not tilted, but the gear produced is still theoretically incorrect, and while it may pass for some purposes, it is in general not good enough for accurate and silent-running gears. Moreover, as the hob is ground down, the degree of tilt has to be varied, and this leads to complications and trial-and-error methods.

Many attempts have been made to modify and improve the radially-relieved hob. One method is to make the hob in two portions, as shown to the left in Fig. 8. The leading portion, which is first fed into the blank, is tapered to break up the cut over several teeth, and this part of the hob acts as a rougher, leaving a small amount of metal on the wheel teeth. The roughing portion is followed by a finishing portion, the characteristic of the finisher being that its teeth are relieved, using a smaller cam than for the roughing portion, thus giving a smaller angle of cutting relief. The effect is that sharpening of the hob does not change its diameter so quickly, and hence it has a longer useful life than a hob with a

full cutting relief. This hob, however, still retains the disadvantages of the previous type, although, of course, to a less marked degree.

In seeking to circumvent this difficulty, one must look for a construction of hob which is such that no change in form takes place after sharpening. The author has had experience of two types of hob which fulfil this requirement, both of which are now being successfully used in practice. Both these hobs remain exactly

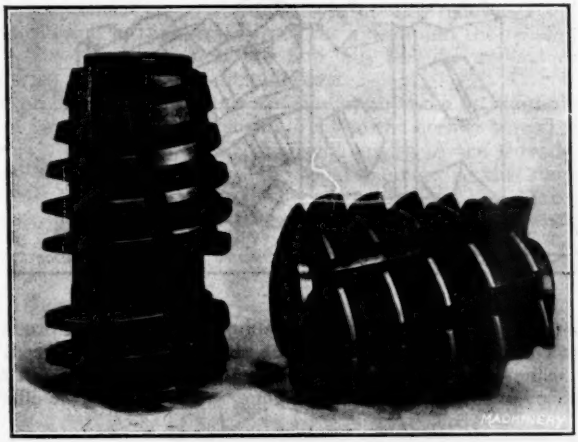


Fig. 8.

similar to the worm at all stages of their life, irrespective of sharpening, and, in addition, they both have advantages which simplify their manufacture and facilitate particularly the profile grinding of the hob teeth.

The Built-up Hob.

The first of these is of built-up formation, and its construction will be apparent from Fig. 10 and the line drawing, Fig. 9. Fig. 10 shows the finishing portions of the cutter, and Fig. 9 the complete hob with a tapered roughing portion. The finishing portion consists of two short rings of teeth mounted side by side with a spacing washer between them. Each of these rings has the same number of cutting teeth as the worm has threads. The two finishing cutters are fitted on the shaft on a sliding key, so that the one cannot turn relative to the other, and their distance apart is dependent on the width of the spacing washer between them.

The teeth on each of the finishing parts are not radially relieved, as in the case of an ordinary hob. Instead, they are side relieved.

When the cutting edges are sharpened by grinding the front faces of the teeth, the teeth become thinner owing to the side relief, but the effective diameter of the hob is not reduced, because the cutting profiles remain at an unvarying distance from the axis of the hob. If only one single row of teeth were used for finishing, the effect

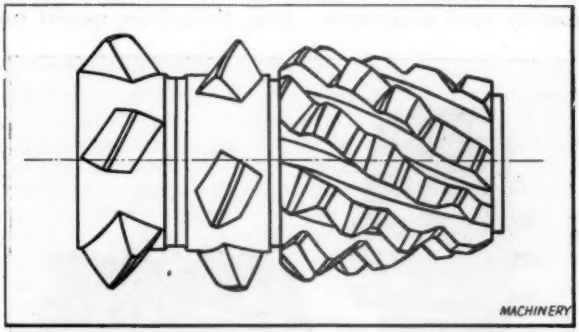


Fig. 9.

would therefore be that, after sharpening, the hob would produce a correct gear, except in so far as tooth thickness was concerned.

By using two rows of finishing teeth, however, this difficulty can be overcome, because the spacing washer gives, in effect, a

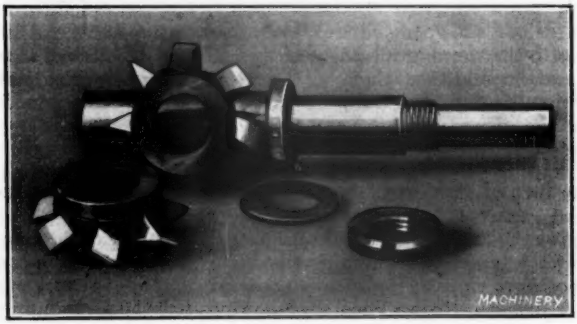


Fig. 10.

means of varying the tooth thickness of the worm. If it is found that, after sharpening, the tooth thickness of the wheel is too great, this is remedied by reducing the spacing collar between the two cutters. It will be obvious, therefore, that this cutter always remains

the same as the worm after sharpening. It also possesses advantages in manufacture which will be discussed later under the heading of hob profile grinding.

The A.E.C. Hob.

The second type of hob, which does not change its form after grinding, is one which has been developed by the Associated Equipment Co. and Mr. E. Jones, the patentees. The hob is very similar, superficially, to the ordinary radially relieved type, the difference lying in the formation of the gashes and the relief of the teeth. The construction of the hob will best be understood by considering the method of manufacture.

The preliminary operations are similar to those on the ordinary type of hob. The hob is first of all cut to the correct thread shape of the worm and then gashed at right angles to the threads and relieved on a relieving lathe in the usual manner. At this stage the hob teeth are as diagrammatically represented in Fig. 11 by the full lines, the front cutting face of the row of teeth shown being

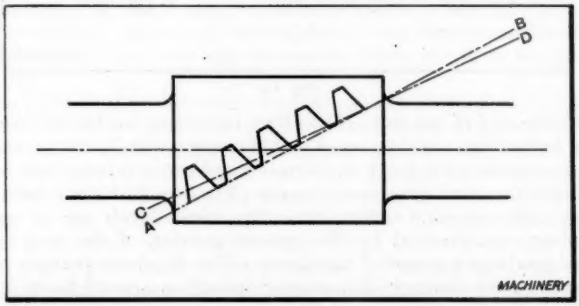


Fig. 11.

coincident with the line *AB* representing the side of the gashing. The hob is, however now re-gashed along a line *CD*, this new gash having a different angle and lead to the original one. The result is to make the teeth effectively thinner at the leading end of the hob, the leading end being the one which is fed first into the worm wheel. So far the thick teeth at the trailing end of the hob are thicker than the corresponding worm threads, to allow for the metal which will be removed in profile grinding of the hob.

The hob is next hardened ready for profile grinding, which is carried out on an ordinary worm-thread grinder, the machine being set up exactly as for grinding a worm. During the grinding operation it will be obvious that the abrasive wheel first touches the hob on the thick teeth at the trailing end and continued grinding produces

a land on the cutting edges at the trailing end. The length of this land decreases progressively from the trailing end and can be arranged to disappear entirely at some predetermined distance along the length of the hob.

The finished hob is shown in Fig. 12. The leading teeth have been untouched by the grinding process and the ground land gradually appears about the middle of the hob and increases in

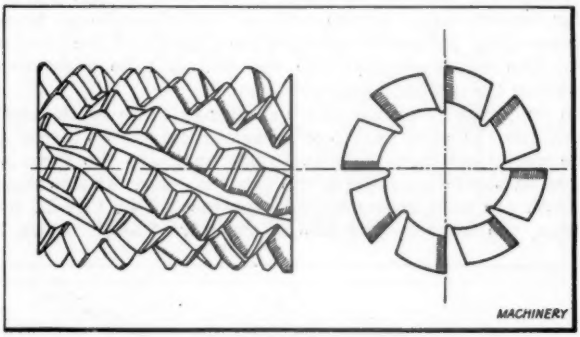


Fig. 12.

size to the end of the hob. The effect in cutting is that the leading teeth, being thin, serve to rough out the worm wheel. As the cutting action progresses the teeth in the middle of the hob come into action and finish the teeth practically to size. The final hob teeth take only a very light cut and ensure that the wheel teeth are of correct formation and finished by the ground portion of the hob to the correct conjugate shape of the worm. This finishing portion of the hob acts in the manner of a reamer and gives a good finish to the teeth.

The hob is sharpened by grinding along the gashes in the usual manner, and it will be obvious that this sharpening does not alter in any way the effective diameter of the finishing portion of the hob; it merely reduces the width of the land on the finishing teeth. It will be noticed that in this type of hob the teeth are appreciably shorter at the front or leading end than they are at the finishing end. Consequently the life of the hob and the number of times it can be re-sharpened are limited by the leading teeth, which in time become too narrow to stand up to the work.

Form of Hob Giving Increased Life.

An alternative method, used by the author, which overcomes this difficulty is to retain the normal gashing of the hob, and to make the teeth at the leading end of the hob progressively thinner than those

at the trailing end. This is done by cutting the two sides of the hob teeth at different leads to the lead of the worm. If one side of the hob thread is cut and relieved at a longer lead, and the other side at a shorter lead, than that of the worm, it will be seen that it is possible to make the hob teeth vary in thickness from a thin tooth at the leading end to a thick tooth at the trailing end. The hob can then be ground at the true lead of the worm, and this will give the effect of a varying land on the teeth, the land having a maximum width at the trailing end and disappearing part way along the hob. The advantage of this arrangement is that it gives the same result as the A.E.C. hob, and, in addition, the hob may be gashed in the ordinary manner at right angles to the threads. Consequently the hob teeth are of constant length and the life of the hob is not limited by short teeth at the leading end.

To meet modern requirements of accuracy and silence in high lead angle worm gears it is essential that the hob be profile ground after hardening. One object of grinding is to correct hardening distortion. Hardening usually distorts the teeth in such a way as to make them un-symmetrical and in many cases also alters the lead of the teeth. A hob which is made solid on its shank may bend considerably in hardening, and the only way to correct these errors is by profiled grinding.

The method of profile relief grinding usually adopted on a radially-relieved hob is to use a relieving lathe with a grinding fixture fitted to the slide. Hobs of low lead angle may be ground with a small disc wheel, but on hobs of high lead angle a pencil wheel is necessary, because a disc wheel would interfere with the succeeding teeth owing to the radial relieving motion. The diameter of a pencil wheel is so small that interference of this nature does not occur ; but, on the other hand, there are many difficulties met with in the use of a pencil wheel. Owing to its small diameter it quickly loses its shape and has to be constantly trued. The wheel being of approximately conical formation, the grinding speed at different points on its periphery varies considerably, and unless the speed of the grinding spindle is very high (60,000 r.p.m. is often necessary) the point of the wheel will not stand up.

Neither of the two latest types of hob described involves such difficulties in grinding the relieved profiles. Both of these hobs can be profile ground on an ordinary worm-thread grinder without the use of a relieving lathe.

Dealing first with the case of the double-tow hob described, it will be remembered that this is side relieved instead of having the usual radial relief. This side relief may be obtained by cutting the sides of each hob tooth on different leads to that of the worm. One side will require a longer lead, and the other a shorter lead, than the worm. The profiles of this hob can therefore be ground on

a worm grinder, one side of the teeth being ground to a longer, and the other to a shorter lead than that of the worm. This process is, of course, much simpler than the grinding of a radially-relieved hob on a relieving lathe, for the following reasons: (1) The diameter of grinding wheel is not restricted, and the use of a pencil wheel is not necessary. (2) No intermittent or relieving action is necessary. For these reasons the double-row type hob can be made more cheaply and accurately than the radially-relieved hob.

The profile grinding of the second type of hob with the tapered flutes is even simpler. All that is necessary is to set up the grinding machines as if for grinding a worm, and then grind a land on the last few teeth. An advantage of this method is that the hob is ground with exactly the same machine settings as the worm, so that the finishing part of the hob is exactly the same as the worm.

Thread Shape.

The question of thread shape must necessarily be involved in any discussion of worm-gear manufacture, because the shape of thread adopted largely decides some of the processes to be employed. The thread shape must also be considered from the technical point of view, because the efficiencey and load capacity of a worm gear certainly depend to some extent on the shape of thread adopted. The question, therefore, arises as to how far the gear efficiency may, if necessary, be sacrificed for the sake of facility in manufacture.

The effect of thread shape on efficiency and load capacity is not accurately known in practice, although certain results have been obtained from laboratory and practical tests which throw a little light on the matter; there is still much room for experiment. The author's design of thread form was tested on a pair of six-inch centre worm gears at the National Physical Laboratory and gave efficiencies up to 98.2 per cent., the average full-load figure for the series of tests being about 98 per cent. The gear box of the Daimler-Lanchester testing machine, on which the tests were made, is not of rigid or modern construction, and it was found that under load the case deflected and allowed the gears to move about 0.006 inch out of alignment. As a gear box of modern construction could be made much more rigid than this, it is safe to say that under practical conditions the efficiency of this type of gear would be at least 98 per cent. The most authoritative data which can be obtained regarding the efficiency of worm gears with other thread forms indicates that the maximum efficiency of such gears is, under practical conditions, not more than about 97 per cent. It seems, therefore, that the shape of thread adopted does make a difference to the performance of the gear, although the effect of this in practice may appear rather small.

It is known that errors in manufacture affect the efficiency of

the gear. If, by sacrificing idealism in thread form, there is a gain in accuracy of manufacture, this sacrifice would, therefore, be justified, because the overall efficiency of the gear would probably not be greatly impaired. This sacrifice is especially advantageous, if in addition to a gain in accuracy, there is also an improvement in production times. It may safely be assumed, therefore, that, for commercial gear requirements, especially in those cases where silence is all important and a small variation in efficiency a secondary matter, accuracy and facility of manufacture should take first place.

Effect of Thread Shape on Method of Manufacture.

In considering the effect of thread shape on the method of manufacture, advantage should be taken of any feature which will simplify the production of the correct thread profile and thereby increase the accuracy with which it is produced. The simplest of all thread forms from a geometrical viewpoint is the one having a straight side on the axial section of the worm, but this is by far the most difficult to produce. Its only advantage is that a worm with this thread shape can be easily tested for accuracy by placing a straight edge at the correct angle, along the axial section of the worm. Apart from this one advantage it has nothing else to commend it. The grinding of this thread shape is a difficult matter on ordinary types of worm thread grinder owing to the difficulties of truing the grinding wheel, which must have a special curved profile. The curve, moreover, must be varied according to the diameter of the grinding wheel. On the new type of grinding machine described in *Machinery*, 45/340—29/11/34, the shape for a straight axial section worm is more easily obtained, because the former for the diamond can be manufactured to give the desired accuracy, and the shape can then be reproduced without difficulty at any future time.

The same remarks apply to the straight normal section thread profile. With the old type of thread grinder, difficulty is experienced in truing the wheel, but this is largely overcome on the new type machine.

The Advantages of the Straight Wheel Profile.

With the advent of the new grinding machine, however, further simplifications are possible. If a straight-sided former is used for truing the wheel, this will produce a thread shape which gives excellent results as regards tooth contact and efficiency. The advantages of a straight-sided former from a practical point of view are considerable. The straight former can be accurately manufactured and easily tested. The positioning of the former on the grinding head is not of such great importance as in the case of a

curved former, because an error in the endwise setting of the straight former does not affect the shape produced as it does in the case of a curved former. Moreover, the position of the diamond point is not critical when using a straight former, whereas with a curved former the diamond point must always be in a definite relation to the former if changes in shape are to be avoided. Even the actual shape of the diamond itself affects to a small extent the shape produced, whereas with a straight former the shape is unaffected by variations in the diamond.

The straight-sided former produces a grinding wheel which is part of a cone on its outer periphery, and this thread shape may therefore be defined as that which would be generated by a conical surface traversing along the thread helix, the axis of the cone being at right angles to, but offset from, the axis of the worm.

With regard to the grinding of hob profiles it will be obvious from what has been said that it is possible to grind the hob at the same setting of the machine so that the hob profile corresponds exactly to that of the worm, and by using one of the modern hob forms, this will retain similarity to the worm after repeated sharpening.

Considering worm-gear manufacture as a whole, it will be apparent that the processes described help to overcome the difficulties which previously existed in worm-gear production. The thread shape which has been suggested lends itself to accurate production in thread grinding by the new process, and at the same time it possesses in itself the mathematical features desirable for giving high efficiency and heavy-load capacity. The new thread-grinding process eliminates the old trial and error methods of obtaining the thread shape, and does not leave everything to the skill of the operator. In addition to this, it has the advantage of increased output and better thread finish. The thread-grinding machine lends itself to the profile grinding of the new types of hob, the combination of the grinding machine and the hob ensuring that the hob is always an exact replica of the worm. The hob itself is not affected by the re-sharpening, and thus is eliminated one important source of inaccuracy with the older types of hob, so that worm-wheel manufacture is placed on a sounder basis.

With the old methods it was impossible to proceed beyond a certain degree of accuracy because of haphazard methods and fundamental theoretical inaccuracies which could not be eliminated. However, once a sound basis founded on theoretically-accurate methods has been developed, it is possible to concentrate on improving the accuracy of machines and tools, and there is no limit to the accuracy which may be ultimately attained.

Discussion, London Section.

DR. MERRITT expressed his appreciation of the privilege extended to him, as a visitor, of opening the discussion. Not the least part of the value of the paper, in his opinion, lay in the indication which it gave of the detailed attention which was being paid to the question of accuracy. As with all other types of gear, satisfactory performance depends entirely on initial accuracy, and the successful application of worm gearing to high-speed drives, as in the case of turbine drives machinery, and close-ratio gears such as camshaft drives, combined with the high efficiencies now possible, clearly show the advances which have been made in recent years.

A further point of considerable importance centres round the question of quiet running. Although worm gears are usually regarded as silent, this is not necessarily the case. Quietness is a function of the accuracy of manufacture and of the peripheral speed of the worm wheel, and to make a high speed, close-ratio worm drive is a difficult matter demanding a very high degree of accuracy.

Considering the paper in detail, it appeared to him that the author had based his conclusions and processes on the unsatisfactory assumption that the hob should be a replica of the worm. This would be justifiable if gear materials and mountings were rigid, but the inevitable deflection under load disturbs alignment and calls for some departure from the theroetical wheel tooth formation in order to preserve satisfactory quietness, tooth bearing and lubrication under load. The practice of David Brown was to use a hob which was definitely different from the worm in order to relieve the entering side of the wheel teeth of load, and although this involves intricate problems in worm gear geometry and necessitates special measuring instruments, experience had shown it to be well worth while.

The author was perhaps unduly severe on the use of a plane grinding wheel. Although the surface finish and cutting capacity are possibly inferior to a cylindrical grinding wheel, the plane wheel has demonstrated the advantages of being capable of speedy and accurate truing both on worm and spur gear grinding, and has the enormous advantage of producing a thread profile which is easily measured along its fundamental straight line.

The author rightly condemned the practice of hand-buffing worm threads after grinding, thereby destroying some of the accuracy derived from the grinding operation. On the other hand, there was probably room for difference of opinion on the desirability of eliminating a final operation after grinding, and a mechanically performed lapping operation which, whilst providing a high polish,

would simultaneously improve on the accuracy of grinding, had been developed.

He also ventured to disagree with the author in his contention that the major errors in worm wheels originated in the hob. There are seven major sources of error in a hobbed gear, and the hob is only one of these, and is incidentally the one which is most easily measured. Only accurate measurement of angular velocity ratios of the various machine drives, combined with angular velocity measurements of the actual gears, permit this question to be definitely answered.

Regarding the general question of tooth form, the advantages of the machine described by the author in respect of production had to be weighed against the necessity for accurate measurement and control of thread profile. The extent to which thread form could be modified to suit convenience of manufacture raises many problems, and depends upon whether efficiency or load carrying capacity (which do not necessarily go hand in hand) is the prime consideration, and it would appear that the use of a thread form derived from a conical abrasive wheel would offer insuperable difficulties both in the analysis of the geometrical properties of the thread and in the actual measurement of the profile in order to obtain consistent production.

MR. J. COHEN: Mr. Walker commenced by stating that worm gears had advanced from the stage of being used only for gear reductions of the order of 20 or more to one to that of gear ratios of four or even one to one. May I add to that statement that it is a perfectly feasible proposition to progress far beyond that limit. In a universal wood-working machine it was desirable to drive the cutter spindle at high speed without the use of a large diameter driving member, so permitting the employment of a cutter of small diameter as for cutting long semi-circular grooves. This was accomplished by mounting a worm on the cutter spindle and driving it by a worm wheel. The ratio of this drive was approximately eight to one up. A similar application was a drive of 12 to one for driving a grinding wheel on a special universal grinder of extraordinary versatility. In both cases high speeds were maintained without the slightest difficulty showing that the drive had a reasonably high efficiency. How different this is from the almost prehistoric cast worm and wheels such as were used in the textile industry, having an efficiency of barely 30 per cent. or so. I mention this to show that worm gearing is not necessarily confined to gear reduction devices or rear axle drives for cars.

The illustrations shown by the lecturer seem to be confined to right angle drives. Again, may I mention that there is no universal need for this restriction. Occasionally it may so happen that there may be some advantage to be gained by departing from the right

angle. It is quite feasible to mount the worm spindle at the same angle as its helix and so use a worm wheel with teeth parallel with its axis. This reduces the end bearing pressure on the worm wheel shaft to that due to frictional losses in the gears only, the end component due to the drive vanishing almost completely. Again I mention this to show that the application of worm drive is not so restricted as many suppose.

I am in agreement with Dr. Merritt in his statement that it is hardly a practicable proposition to make the worm wheel hob a replica of the worm. If the worm wheel ran perfectly true, was positioned accurately, and did not deflect under load, and if the same applied to the worm, and in addition the casing were perfectly rigid, then and only then would I agree with the lecturer. It is my contention that if the hob is slightly oversize a slight misalignment or displacement will not have the effect of causing excessive local pressure at the ends of the wheel teeth. In addition, there would be the beneficial effect of a wedge shaped film of lubricant immediately prior to the point of full load. It seems to me that in many cases the worm wheel is made much too wide. The extreme points of the teeth cannot contribute much to the load carrying capacity of the gear. Would it not be an economy to turn the wheel with a straight face and leave it to the hob to form only a slight hollow in the centre of the wheel. We should then get all the bearing surface that could be of any real utility and still have the advantage of a wide tooth to diminish deflection.

It is easy to appreciate some of the disadvantages of grinding worms by a flat-faced wheel. A small wheel requires frequent truing, whilst a larger one tends to deflect away from the cut and so requires quite a large number of passes to finish the work. Too large a wheel may cause interference with the shape of the thread. Another difficulty lies in providing a mounting of sufficient rigidity on account of the numerous adjustments to be made.

The worm grinding machine illustrated seems to have many good points. It carries a wheel of large diameter which cuts on its periphery, both points conducive to long intervals between wheel truings. There seems to be no reason why the bearings cannot be exceptionally generous in their proportions again conducive to rigidity and consequent high production. Naturally, there must be some restrictions to its utility. Can the lecturer give some idea of the proportionate dimensions of the grinding wheel and worms to be ground.

The illustrations are all of the type of gear used in car axle drives.

How does the lecturer propose to deal with a worm formed integral with a flange ? The worms shown are mounted on centres and presumably have to be reversed end for end for finishing. What provision is made for grinding a worm from its own bearings.

Judging from the naturally casual glimpse to be had of the photographs it seems that a deeply dished wheel may satisfy these requirements to a certain degree.

A point in favour of the machine is that any grinding marks that may be left are in the direction of the worms rotation and should have the minimum of destrictive effect on the wheel in use. At the same time I find it hard to take as literal the statement made that after a second grinding cut on a worm where 0.15 in. has been allowed for finishing to size no sparking is visible. A very small excess of metal, say of the order of .00005 will give a visible spark. To give an extreme case in the opposite direction I may state that some time ago when experimenting with internally grinding a six-inch gun sleeve, sparking continued half an hour after stopping the radial feed. Naturally this was due to the impossibility of providing anything approaching a rigid mounting for the wheel.

There seems to be another advantage of the machine that the lecturer did not stress. Owing to the large diameter of the grinding wheel very little variation in shape should occur in the tooth form should the diamond not be mounted in its correct position. Regarding the novel form of hob there are one or two points I should like to be made clear. There is, of course, no circumferential relief possible if the hob is to retain its diameter. Is this defect of any importance in use? I can imagine some materials where this point may be of great importance. Since the two parts of the hob are necessarily separated is there any detrimental effect due to the cessation of load and its reimposition as the second portion comes into action? What provision is made for gauging the relative end positions of the two halves? Should one half be damaged or broken is it possible to obtain a replacement or must a complete pair of cutters be obtained?

The A.E.C. type of hob seems to comply with the lecturer's requirements as regards keeping its diameter, but its life seems to be restricted to that of the width of the land on the finishing teeth. Is there any way of minimising this defect? Finally, may I ask a direct but possibly impertinent question. What is the use of the machine tool maker going to all the trouble of making an almost perfect machine and cutter if the user does not supply an accurate and rigid mounting for the gears?

MR. E. J. H. JONES: I am somewhat surprised in listening to some of Mr. Walker's contentions, particularly when he refers to the efficiency of close ratio drives for commercial vehicles, and that these have been made possible by the accuracy to which worm and wheel can be made, due to recent developments. He went on to say, also, that worm gears are being used where bevel or spiral gears were previously used on applications of all classes of machinery. I would suggest to him that, in connection with the last part of

that statement, the reverse is the case. Where high speed, heavy load and sustained effort is required, users are changing over from the worm and wheel to the double helical and spiral bevel drive and if Mr. Walker will refer to the United States he will find this tendency to an even greater extent than in this country. It has been contended this evening that the accuracy to which these parts can be made is due to recent developments; I can assure Mr. Walker that users who manufacture in large quantities, have had to get down to this accuracy for some considerable time.

In obtaining the degree of accuracy about which we have talked this evening, I am inclined to wonder sometimes whether or not we are flogging a dead horse. Even with such accuracy, when troubles occur, the experts tell us several things: (1) That we should offset our worm with our worm wheel in order to compensate for expected deflection when under load, or again that we should alter the tooth helix slightly on the worm wheel, in order that there is clearance on the entering side of the worm to give oil an opportunity of getting between the two faces. These proposals, of course, tend to nullify the accuracy of the mating worm and wheel. Nevertheless, I think it is very definite that where the conditions referred to above are required, the worm wheel is inadequate, and it is only by the greater accuracy to which these parts have been made for some years past, that it has been kept on its legs so long. The worm and wheel was a fairly satisfactory arrangement a few years ago when it was transmitting 45 h.p. but now that we are pushing 130 h.p. through the transmission, at the same centres, it has become necessary, in certain instances, to use an alternative form of drive.

Mr. Walker has brought forward, however, one new machining arrangement, but this has been found necessary, I have no doubt, because of the difficulty of grinding by other means, a worm where the tooth shape is straight sided on the normal section, but on any other types of worms the machine would, I consider, present difficulties for two outstanding reasons, one being the difficulty of determining the curve or combination of curves to which the grinding-wheel former must be made, in order that the wheel is the correct form to produce the shape required when grinding on the normal section. On certain other types of worm, this curve will change in relation to the helix angle employed. It is difficult to see how the shape of this former can be determined mathematically and it seems probable that trial and error to some considerable extent will be necessary to obtain perfection. Secondly, it becomes necessary that this former be set in precisely the correct relationship with the grinding wheel—and this is no easy matter. The machine shown by Mr. Walker for this operation is, I have no doubt, quite satisfactory for this one worm shape but would, as

I suggested above, be particularly difficult to manage on any other shaped worm tooth.

Mention has been made of the Jones-A.E.C. Hob and its " length of life." I can assure the meeting that the life obtained from this type of hob is really remarkable. I have just had an opportunity of examining two hobs which have machined respectively fifteen and sixteen hundred worm wheels, approximately 12 in. in diameter, and the wear which had taken place can be readily computed by the amount of the " land " which is being absorbed or reduced by grinding, and it seems probable that the hobs are capable of finishing well over ten thousand worm wheels. This can be easily understood when it is pointed out that the width of the " land " on the thickest end is usually not less than three-eighths of one inch. The slide which was shown of this type of hob did not do justice to this feature. It should be mentioned, also, that the hob should be reground with a pencil wheel so that each point of the cutting edge is in its correct position radially on the helix angle. It may be of interest if I mention that I have made several of these hobs, when used for finishing only, in Nickel Chrome Case Hardening Steel instead of the usual High Speed Steel, with a consequent saving of approximately £10 in material. It is also an economy where large numbers have to be produced, to rough out with one hob provided with more taper and a bigger cam on the relief, providing a second hob for finishing, without taper and less cam.

You will, most of you, remember the days when our milling cutters were little more than rotating files on which two or more teeth passed over the work, distending the arbor and the machine generally, until sufficient load was applied to force one tooth under the cut. The multi-tooth reamer hob referred to by Dr. Merritt would, I should assume, perform in like manner, giving a result depending upon the rigidity of the machine and the condition of the bearings.

Mr. Summers : The use of worm gears was known to the ancient civilisations but it has taken some 2,000 years to bring them to some degree of perfection and each improvement has really been the application of the machine tools of the period. The machine tool of our own period is the grinding machine and the author has shown how best we can apply it to this manufacturing of worm gears.

I am in entire agreement with his criticism of the method of grinding shown in some of his illustrations but I am bound to say that the flat sided wheel shown has been and is being used with great success. With suitably graduated heads of reasonable size and a set of calculating tables, a tooth shape of the highest accuracy can be produced and reproduced regularly. The wheel can be trimmed to give a special tooth shape but for my own part I do

not like such innovations. In the course of my work I have examined many of these special tooth forms and have never yet found one that was better than an involute and the great majority were very much worse.

The rim type of grinding wheel has, so far as I know, only one limitation—it cannot be used for worms of fine pitch on account of interference. But for moderate and coarse pitches it is undoubtedly excellent and represents a real step forward.

I was astonished by Mr. Walker's claim that .010 in. could be entirely removed at one cut by the rim type wheel but I suppose it was speaking comparatively and that actually some .001 or more would be removed by subsequent pass without feed. On the disc type grinder an accuracy of .0002 or less can be easily obtained so that one or two idle cuts would probably be well worth while.

The author frankly admits the difficulty of grinding hobs so that they will produce worm wheels of the true involute shape. It may be shown by simple geometrical consideration that gears having an arbitrary shape must run at designed centres. However, with such a small deviation from the true involute and with gear cases accurately bored to centres the only real objection is the wear in bearings. At the present time nearly every worm gear is fitted with ball and roller type bearings, the wear on which is almost negligible, so that despite a very real objection to gears which do not conform absolutely to the involute curve, I think that in this instance it may be permitted to pass on the ground of expediency.

In his remarks Dr. Merritt referred at some length to deflection in gear cases and the precautions taken by his firm to allow for same. To use a hob slightly larger than the worm may be satisfactory in a regular production job for the results can be obtained by trial and error, but in an ordinary commercial application the cost would be prohibitive. Also the beneficial effect of enlarging a hob could be argued and I submit that the carrying of a still greater number of tools than is at present required is not worth while on so debatable an issue.

Mr. Walker has made only slight reference to the question of materials for gears and the tools for producing them. I for one would much appreciate his comments either now or in the subsequently written discussion, on the use of materials hardened by low temperature impregnation which material should, I think, be excellent for worms. Finally, I would like to pay a tribute to the author, whose work has done so much to improve the worm gear, which, though it will never achieve the efficiency of a double helical spur gear, may possibly at some future time oust bevels and spirals from the place they now occupy.

Mr. V. Gartside dealt with questions concerning the profile of

the teeth, the interchangeability of worm gears, and the "hunting tooth."

MR. SWINN also put a number of queries to the lecturer.

MR. WALKER: Dr. Merritt has misconstrued to some extent the main theme of my argument with regard to hobs. The point I wished to stress in the paper was not so much the provision of a hob as an exact replica of the worm, but the provision of a hob which does not change its form after sharpening. Even so, however, I maintain that on the majority of worm gear applications, such as turbine drives, machine tool applications, etc., where loads are not excessive and where the gears are only required to run in one direction, it is far better practice to make the hob of the same size as the worm and allow for deflection (which invariably takes the form of a sideways separating movement of the worm and wheel) by offsetting the wheel. Using this method, a full face contact under load is retained. It is impossible to estimate the probable deflection of a gear housing and its bearings, and I fail to see why an error of known magnitude should be introduced into the gears to compensate for an unknown error in the mounting, and in view of this unknown quantity it is difficult to see the use of the solution of intricate problems in worm gear geometry.

Automobile gears belong to a class in themselves, partly owing to the fact that they have to carry loads on both sides of the wheel tooth and therefore deflect in opposite directions according to whether drive or overdrive is in use, and partly owing to the very heavy loads which have to be transmitted in low gear. I cannot help thinking that the ultimate solution of this problem lies largely in the hands of the automobile manufacturers in the provision of more rigid housings for the gears, and Mr. Jones' contribution to the discussion seems to show that his company have progressed a long way in this direction as they evidently find that a dead size hob gives excellent results.

Dr. Merritt admits the superiority of the cylindrical grinding wheel over the plane wheel as regards surface finish and cutting capacity but suggests that the plane wheel has the enormous advantage of producing a particular tooth shape. Experience of the Holroyd thread grinder with its cylindrical wheel has proved it to be equally facile in the production of an involute thread shape as is any other machine, and it has the additional advantage that it can accurately produce a multiplicity of other thread shapes which cannot be dealt with on other types of grinder. The cone-generated shape is a further refinement rendered possible by the machine.

Mr. Cohen's references to worm increasing gears applied to woodworking machinery are interesting. The author's company were once testing a 20/1 ratio gear by driving the worm from a motor

and taking the output from the wheelshaft through a dynamo; owing to one of those accidents to which the best of electrical experts are prone, the direction of drive was reversed, and the dynamo, acting as a motor, drove the unit as an increasing gear under 100 per cent. overload throughout a whole night. It was discovered the following morning rather heated but no worse for its experience.

One of the reasons for making a worm wheel with a wide face is to give an ample area of metal under the teeth to resist the tension induced by the load. I am in agreement, however, with the cutting down of the amount of metal above the throat as this is not of much value as bearing surface, and in any case tends to make the teeth come to a point at the top; pointed teeth are to be avoided as they are liable to crumble away and form a starting point for pitting.

The less frequent intervals of truing, and the large rigid bearings on the new Holroyd patent thread grinder, are advantages which tend to more rapid and accurate production. Two sizes of grinding wheel are provided for on the machine, one being 20 in. and the other 28 in. diameter. It is found, however, that either of these will cover the majority of requirements. The range which can be covered is from about $\frac{1}{4}$ in. pitch up to $2\frac{1}{2}$ in. pitch and any number of threads from single thread up to multi start worms of 20 in. lead.

Mr. Cohen also inquired as to the possibilities of grinding a worm formed integral with a flange and I assume that he refers to a wormshaft with a flange at one end larger than the diameter over the worm threads, and the consequent possibility of interference with the grinding wheel. Such a worm can be accommodated on the machine by making use of a swivelling device on the grinding head which allows the axis of the wheel to be revolved in a horizontal plane. The same method holds good when grinding a worm from its bearings, and a wheel dished deeper than the tooth depth is unnecessary.

In referring to a second passage of the grinding wheel producing no sparking effect, I was speaking comparatively and comparing it with a disc or plane grinding wheel. With the latter type of wheel the machine can be left running for several passes without putting additional cut on, and it will still look like a pyrotechnic display. The practice with the Holroyd machine is to go round the worm twice, the second time being without additional cut, and this proves to be all that is necessary.

There is a circumferential relief on the double row hob, and consequently reduction in diameter after sharpening but this only reduces the bottom clearance between the worm and wheel, and does not affect the essential part of the hob profiles. The cutters

should be made in pairs and the two halves are adjusted after checking their relative positions by means of a dial indicator set on a worm thread grinder. There is practically no cessation of load between the two halves of the cutter, but nevertheless, it gives its best results on a very rigid machine.

The life of the A.E.C. hob is naturally restricted by the width of land, but as Mr. Jones has pointed out, the slide which I showed may not have done full justice to the actual width used in practice. Mr. Jones' remarks regarding the modern tendencies in the uses of worm gears as compared with spiral bevel gears are naturally based on his experience in automobile work, which represents only one of many industries using gears. As one who has opportunities of observing the tendencies of all classes of gear user, I can assert that, in spite of a momentary reaction against worm gearing in the automotive industry, there is a general urge in the direction of worm gears for most other classes of work.

I would not for a moment belittle the vast amount of work which has been done by the automobile manufacturers in improving gear manufacture, but at the same time I think some credit should be given to the gear specialists who build the machines and evolve the basic processes of manufacture. I know of no single instance in which the automobile manufacturer has evolved a lasting improvement in gear manufacture. Such machines as the Maag spur gear grinder, the Gleason spiral bevel machines, the Sunderland gear shaper, the Cornelis thread miller were all evolved by firms specialising in gear production.

I believe that the new Holroyd Worm Thread grinder is another step in the right direction. There is certainly a little initial work to be done in making the former to produce a required thread shape, but it presents no insuperable difficulty and the disadvantage of an hour's preliminary tool room work is far outweighed by the advantages which obtain after the work has been carried out. A saving of 60 per cent. in production times is no mean consideration, and this is coupled with the certainty of always being able to reproduce the thread shape to very fine limits without any trial and error.

Mr. Jones' second objection to the grinding machine is not quite clear. The former is dowelled and clamped at a definite distance from the axis of the worm, in other words the diamond always moves in a fixed path relative to the worm axis. The position of the grinding wheel in relation to the former and in relation to the worm is therefore automatically made correct by the operation of truing the wheel. The wheel is brought up to the diamond, and not vice versa.

In reply to Mr. Summers, I agree that the flat sided grinding wheel has been used with some success in the past, and it will naturally

die very hard as it has become ingrained in engineering practice. The only limitation of the annular grinding wheel when applied to worms of fine pitch is due to the necessity for the provision of a wheel whose tip is narrow enough to pass through the width of thread space at the bottom of the worm, and in this respect of course it is no more limited than any other type of grinding wheel.

In considering the depth of cut which can be removed at one pass of the wheel over the worm thread, it is to be remembered that the grinding action is in a way different to most other grinding practice in that the speed of traverse is comparatively slow. It is found better to use a slow traverse and heavy cut than to use a fast traverse with a light cut, the increase in permissible cut being in far greater proportion than the reduction in speed of traverse. This is made possible by exceptionally large grinding spindle bearings and a powerful drive, and it brings with it the additional advantage of a lower number of grinding strokes and reversals, with consequent less wear and tear of the machine.

The use of material hardened by low temperature impregnation is useful for certain classes of work where minimum distortion is necessary and for small pitch gears in which the thread space is too narrow to admit of thread grinding. Under heavily loaded conditions, however, there is a tendency to flaking on the surface of the worm.

Mr. Gartside has stressed the difficulty of manufacture encountered in the straight axial section worm and there is no doubt that the difficulties are very real. The advent of the new grinding machine of course reduced these difficulties very considerably but there seems no object in retaining a thread form which has no outstanding features apart from its ability to be checked easily. If a worm wheel is cut by means of a hob I do not think that a " hunting tooth " is necessary but if cut by means of a fly cutter then a hunting tooth is advantageous from the point of view of cutting time and accuracy. I do not know of any experiments which have been made to determine the relative effects in practice of the hunting tooth but I should think that with equal accuracy in both cases the gear without hunting tooth should show some improvement. Unfortunately a worm wheel without hunting tooth is more liable to error, and it is doubtful whether the advantages of each tooth always mating with the same worm thread would overcome the disadvantage of greater initial inaccuracies.

In reply to Mr. Swinn, the best all round results appear to be obtained by using a mean pressure angle of about 25 degrees, but this depends on the ratio and lead angle of the gears. With the involute shape of thread, a basic pressure angle of 20 degrees on the normal section at the pitch line covers the majority of requirements. The relation between the number of threads in the worm

and gashes in the hob is not very important where the hob is used with a tangential feed into the worm wheel. In some old types of gear cutting machine a radial feed only is provided and it is then important to avoid a common factor in the number of threads and gashes in order to provide as many different positions for the cutting edges as possible.

Projection of the normal tooth profile is useful for checking purposes provided the front cutting face of the gash is radial and allows the cutting edge to be in the flat plane of the field of the projector. This check is, however, not necessary if the hob is ground on the thread grinder after setting the machine in such a way that it has correctly ground a test worm.

Regarding the worm grinding machine, the discussion in general seems to have shown that most contributors appreciate the features of the new method of grinding as regards its practical advantages in cutting capacity and finish produced but some doubt has been expressed as regards its ability to compete with the plane disc grinder in producing an involute shape. I can assure the meeting that practical experience with the machine in grinding involute threads shows it to be in every way superior to the old method, and that the results obtained are more accurate and consistent.

INAUGURAL MEETING OF THE LEICESTER AND DISTRICT SECTION.

THE Inaugural Meeting of the Leicester and District Section of the Institution was held at the College of Technology, Leicester, on October 3rd, 1934, at 7-30 p.m., Sir Walter Kent, C.B.E., President of the Institution, in the chair.

SIR WALTER KENT: I am only taking the chair to-night until we come to the lecture by Dr. Anderson when I will have great pleasure in calling on your Section President, Mr. Hallam, to take charge of this meeting.

The reason why we are hoping that the new section that is now being inaugurated here may grow to be a branch equal probably in number to any of the other sections which are already established about the country is that Leicester is a centre almost unique in the trades that are combined within its boundaries, and therefore the engineering problems that are presented to engineers who are working in Leicester are different from what engineers about the country have to face, and it is felt that you ought to have a production engineers' branch here so that you can understand and grapple with the difficulties of your own particular trades, because by that the object of this Institution, which is to further the interests of Industry, can best be served.

On Monday it was my privilege to be in Manchester when Sir Herbert Austin gave us a most interesting paper on the effect of design on mass production. Last year I was in Manchester at their opening meeting and there were 700 people present, all engineers. On Monday night, unfortunately, the local branch was unable to get the use of that room, the biggest room they could get only held 350. Well, it was absolutely crowded, and they had to refuse as many again. That shows the interest that one of the Institutions has created and is maintaining, because that branch has now been going on for four or five years. So I do hope that Leicester will do equally well. It has an equal opportunity and for the reasons to which I have just referred, there is the need as well as the necessity to have a successful branch of the Institution of Production Engineers here in Leicester as there is in Manchester or any other part of the country, and I do appeal to all of you present if you have not already done so to look into the work that the Institution has done and is doing.

I was looking through papers of the Institution a few weeks ago in order that I might prepare some remarks for my Presidential address this year, as I have to deliver a speech in Scotland shortly,

and I came to the conclusion that everything conceivable had been said, and what on earth I was to say I did not know. I just mention this as giving some proof of what I was meaning that there is definitely good stuff in the papers of the Institution which no engineer can read and not profit by. Still, I know that fresh ideas will crop up day by day and I hope among you here there may be many who will join the Institution and give us papers from time to time that will add to the sum total of knowledge that this Institution is gradually building up. I do most earnestly trust that you may be filled with the same faith and hope in the work that this Institution can do for the country that I have myself.

Mr. N. A. Cullin, Hon. Secretary, read numerous telegrams and letters wishing success to the new Section.

Mr. H. Hallam, Section President, proposed a resolution welcoming the formation of the Leicester and District Section. In his opinion there was room for a good branch in Leicester, and although he did not yet know very much about the work of the Institution he had read some of its published Proceedings and found them well worth studying. He strongly urged those present who were not yet members to consider the question of joining the Institution.

Mr. Mark Taylor seconded the resolution.

Mr. S. Carlton Smith, Chairman of Council, said that those of them who had been members of the Institution for a good many years have the greatest confidence in its future. In the past few years it had made great strides, and even during his two years as Chairman of Council he had been present at the inauguration of no less than five new local sections.

Mr. J. D. Scaife, Past-President and Member of Council, said that although he had been a member of the Institution since its inception he could assure them that new viewpoints were always arising and the accumulation of valuable technical knowledge was always being added to. The Institution was started because none of the older institutions catered adequately for the expert engaged in scientific manufacture. It was doing a great work, and he felt sure that the Leicester Section would be a worthy addition to the large number of branches they now had.

The resolution having been adopted unanimously, Sir Walter Kent vacated the chair to Mr. Hallam, and Dr. Anderson then read his paper on "The Training of a Production Engineer."

INAUGURAL MEETING OF THE SOUTHERN SECTION.

SIR WALTER KENT, C.B.E., President of the Institution, who presided at the Inaugural Meeting of the Southern Section of the Institution held at University College, Southampton, on Wednesday, October 17th, 1934, said that he would not give anything in the way of a formal address as they were later to hear a most interesting paper by Dr. Anderson on "The Training of a Production Engineer." Close acquaintance with the work of the Institution, such as he had, would convince them that it offers many facilities to engineers, both young and old, that should not be neglected. It brings to all who are interested in the art and science of production very real assistance.

It was because they wished to place at the disposal of as many production engineers as possible the facilities which the Institution afforded that they had adopted the policy of establishing local sections wherever there was sufficient engineering production to justify the effort.

He would not for a moment belittle what the "Civils" do and the "Mechanicals" do, but they deal more with the theoretical side of engineering. It is by her industries that England pays her way. Now it is very obvious when one thinks of it for a moment that to turn those goods out most efficiently and most cheaply is an absolute necessity to a country like ours that is so dependent upon the result of productive industry, because everything hangs on that. If we did not produce in such a fashion that our goods were desired both at home and abroad, our great selling organisation, our great distributing organisation, would have nothing to do. They were still reminded by going down Southampton Water what the effect of the depression of the world's industry and British industry means to the carrying trade of the Mercantile Marine of Great Britain. The importance of that Mercantile Marine he would not dare to attempt to describe to an audience of people living in Southampton.

Those who have read the papers that are contained in the Proceedings of the Institution, would support him when he said that there was a mass of real information that was going to help anybody who had the responsibility of turning out mechanisms, great or small, in the best possible way, in a manner and to an extent that will make him grateful to the Institution that had provided that help. They could not advertise themselves in the way that they might if they were a commercial institution. They

aspired to be a purely scientific body, but he would ask all who feel that there is something to be offered to the engineer by the Institution to tell any friends who are engaged in similar lines of work, of the good that is at their service if they like to stretch out a hand to take it, and get them to become members.

He might perhaps be permitted to remark that when Sir Herbert Austin read a paper at the Manchester Section some two or three weeks ago he referred to the dirth of skilled men that was already felt, and which in all probability will be felt to a far greater extent. To supply that want is, he thought, one of their jobs and that was a direction in which this Institution could render very great service to the country.

Mr. E. L. Forge, Hon. Secretary, read a large number of letters and telegrams wishing success to the new Southern Section.

MAJOR STANFIELD, President of the Section, said he felt that Sir Walter Kent had been more than considerate to him, and, incidentally, also to all present, in that he had left so little to say about the Institution of Production Engineers that could be of any possible value. This was obviously as it should be. Sir Walter Kent had an extensive knowledge of the aims, objects, and ambitions of the Institution which had been obtained by the kind interest he had taken in the Institution for a number of years. Some of them had yet much to learn. If any evidence of the interest created locally in the Institution were necessary it was to be found in the representative gathering there to-night of gentlemen who hold responsible positions in some of the largest and most progressive engineering works in this district, and without whose interest and co-operation the Southern Section of the Institution of Production Engineers could not have been brought into being. Among those gentlemen he would particularly mention Wing-Commander Cave-Brown-Cave, who had shown his practical interest in so kindly affording accommodation in the College to the local section, and by whose favour they were there to-night.

He knew that he was voicing the feelings of the members of the local Committee in stating that it is their ambition that the Southern Section shall become one worthy of the great cause of the Institution, that of imparting knowledge to those engaged in engineering who were responsible for the producing of the goods, and in so doing eventually become a valuable asset to those engaged in engineering in that district.

It was a great pleasure and a privilege to have the opportunity of proposing that this meeting welcomes the inauguration of the Southern Section, and wishes it a successful future.

MR. WESTBROOK said he was afraid this was rather a surprise attack on his speech-making efforts which as they would see were practically useless. This was the Inaugural Meeting, and they had

had a certain amount of difficulty in, should he say, canvassing people. They wanted all present to gain as much knowledge about the Institution as possible, and he hoped that as many as could do so would become members. He had much pleasure in seconding the motion as brought out by their President, Major Stanfield.

The resolution was put to the meeting and adopted unanimously, after which Sir Walter Kent vacated the chair in favour of Major Stanfield. Dr. Anderson then gave his paper on "The Training of a Production Engineer," already reported in *The Journal*, Vol. XII, page 178.

Discussion.

WING COMMANDER CAVE-BROWN-CAVE: This new Section has been very wise in arranging for Dr. Anderson to give the first lecture on Training. A discussion among production engineers of what knowledge the junior members should acquire is one of the most useful functions of the Institution. Dr. Anderson's address has been remarkable in that he has laid down what in his opinion is the knowledge which should be conveyed to the production engineer during his formal training. In this connection I would point out that it is wrong to assume that a student's training finishes when his formal training is complete. It should be continued at any rate to his retirement and possibly later still. I think that the items that should be included in his formal training are mainly points of principle, and that factual knowledge can very largely be left to that part of the training which he carries out himself after his final examination, and which continues for many years.

If you modify the very imposing list which Dr. Anderson has laid down by the omission of a good deal of the factual knowledge, you get a much more manageable total, and I agree with the inclusion of all the principles to which he has referred. He has made a much better selection of the important principles than I have heard propounded anywhere else. I think that his suggestions are applicable to almost all engineers up to the stage of Ordinary, if not the Higher National Certificates.

He started by defining the mysterious phrase "The Production Engineer," and Sir Walter in his opening remarks said something about the relationship between this and the other engineering institutions. I do not know if I was correct in understanding Sir Walter to say that the *Mechanicals* and *Civils* dealt with the theoretical aspect rather than the practical aspect. If he refers to the Royal Charters of these Institutions he will find that he is wrong. I hope that he will not think me in any way lacking in good manners if I express my complete disagreement. That is a very difficult thing to say, and I hope he will pardon me for saying it because it is important.

Returning to the question of what subject should be included. It seems to me that economics is of very doubtful merit. To what extent does the junior production engineer require economics in the form in which it is normally taught to engineers? Is it not true to say that the kind of economics is more proper to the works manager or perhaps the managing director than the junior production engineer? Let me take a naval simile: you are rather

inclined to teach the sub-lieutenants the admiral's job. This is dangerous in two ways. Partly because it leads to undue criticism and partly because by the time these subs get to be admirals they will think that their knowledge is still up to date. They will not think it necessary to keep themselves up to date in the art of being admirals, and they will take on their jobs partly out of date. Now if you teach something rather different from the economics that is taught at present you can give something extremely useful. Economics taught at present contains the subjects in which those people who outline the syllabus are interested. These people are either approaching the admiral stage or at any rate are very interested in it. I think they have got to go back and remember the kind of things they were not taught at the age of twenty years but which they wanted. Now I have applied that process and come to the conclusion that the kind of thing that would have helped me most is very different from economic theories.

The difficulties which a student going out meets are much more in matters of general common sense and general dealing with men. If he could be given some "sea-daddy's" advice on his dealings and relationships with his subordinates, his equals, and his seniors, I think it might keep him out of a whole host of trouble and greatly improve his effectiveness. You may not be able to lay down definite principles which can be followed but if you can show him that these problems are things that he must study, you have gone a very long way to starting him on the right road. You can explain to him the importance of clear and explicit instructions and of defining the responsibilities of individuals and various points like that.

I think that Dr. Anderson has if anything erred in making his paper too wide, but it is always wise in putting up a basis for discussion to build a thing too large and then cut off the unnecessary bits. Whether that is sound production engineering I rather doubt but I have seen it followed. May I conclude, Sir, by expressing my great admiration for Dr. Anderson's paper and by emphasising the very great service he has rendered ?

Sir Walter Kent : I would like just to break a lance with Wing Commander Cave-Browne-Cave regarding the two senior institutions. It is their job to provide the railways, the reservoirs, the canals, the roads, the bridges, and all those things that are essential attendants upon the work of the production engineer, but it is the production engineer who is turning out the British goods upon which the welfare of the country depends. It is his products that pay for the running of the nation. I am not in any way belittling the work of the other bodies. Without it we could

not get on, but the actual job of the production engineer is providing the wealth by which Britain exists.

MR. WESTBROOK: I would like to elaborate a little on Wing-Commander Cave-Browne-Cave's remarks. I think a great deal is lacking usually through people dealing with production in the works not getting down to the psychological aspect with the men with whom they are dealing. To one man you have to give a definite instruction, another man you have to lead up the garden path, as it were.

MAJOR STANFIELD: I do not think that Mr. Westbrook agrees with the expression "tact" as meeting that which he wanted to convey to us. There is a lot in what Mr. Westbrook says. There are men whom we come across, awfully good fellows if you lead them, and awfully bad fellows if you drive them. They won't be driven, and I do think that in the smooth running of any works tact plays a very great part, in which the man who is responsible for controlling the labour under him, if he is tactful, can get very much more out of his labour than if he is not tactful.

DR. ANDERSON: I agree with Wing-Commander Cave-Browne-Cave as to what we ought to train our sudents to do in the technical institution. The training should be such as to enable them afterwards to continue training themselves. Their training never really ceases, it goes on all the time, and I think I said that what was required in industry was people who think clearly and logically, by careful analysis separate cause and effect, and this is really what our training should aim at.

I appreciate that my remarks probably gave too much weight to the factual knowledge as compared with the principles. If one got down to it and brought out a detailed syllabus probably that would not be so. A student can, to a very large extent, get his factual knowledge from his own reading, and from his shop experience. I agree also that some part of this might well be included in National Courses which I feel are too academic in many ways.

I am glad that Wing-Commander Cave-Brown-Cave agrees with me on the subject of economics. As a rule I find myself in the minority of one there. It is undoubtedly a fashion to look on economics as a most valuable subject. Actually so far as the young engineer is concerned there are many subjects much more valuable. What is wanted undoubtedly is something on the psychological side. The subject calls for a whole session on it, perhaps a few lectures coming under some section may deal with that particular aspect, but undoubtedly a student does need instruction on how to deal with people, and I believe that it could be taught just as much as some of our other subjects can be taught if one can get the right approach. Mr. Westbrook raised the same point. I was interested in Sir Walter Kent's reference to the jig borer machine.

There are quite a number of these amongst the manufacturers. They are very marvellous machines indeed, and I always look at them with a slight feeling of sorrow that apparently they cannot be made in this country. I think it is one of the things which the Institution of Production Engineers might take up.

MAJOR STANFIELD : Before we dismiss this subject there is just one thing which comes to my mind in respect of it. We have heard from Dr. Anderson that the necessary time for a student to put in to become a production engineer is roughly five years, after which he goes into the shops, and I take it before he can become efficient he has another five years. I am just wondering when he commences to earn, and at what time he should start his career as a production engineer. I wonder whether Dr. Anderson would just give us some idea.

DR. ANDERSON : The five year course which I suggest is taken concurrently with the shop apprenticeship, so that at the age of about 21 or 22 he has completed his technical college training and his shop training, and about that age I think he would then be entitled to begin to look for a job of minor responsibility. It is not a question of taking five years in the college and then five years in the shop afterwards. His training is taken concurrently with his apprenticeship, the college training being taken in the evening classes. The majority of students come under that system.

MR. CARLTON SMITH : I have sat on various committees for a long time, and am quite aware of the existing courses. I have helped to draw up the syllabus and examination in some cases, but the course you have outlined is far more comprehensive, or else it is a more masterful survey of all yet that we have undertaken. It is essentially the course designed to cater for the Graduate examination of the Institution. Perhaps you would tell us in how many colleges these courses are now in operation.

DR. ANDERSON : I think, Mr. Chairman, I can assure you and Mr. Carlton Smith that the next step is being taken, and in a large number of colleges throughout the country courses in production engineering have been set up. London, Birmingham, and Wolverhampton were the first to start, and their example is being followed. I think some 30 or 40 colleges throughout the country offer courses of the type that you outline, and the students are taking the machiners', turners', and fitters' work which is the one in which your representatives are collaborating. I am also talking of your own Graduate examination.

MAJOR STANFIELD : Well, gentlemen, I feel that we owe a very great vote of thanks to Dr. Anderson for a most interesting and instructive lecture, and also to those gentlemen who have promoted discussion in respect of it. Also we owe a vote of thanks to Sir Walter Kent and Mr. Carlton Smith for coming all the way down

here from London to help us in this, our first meeting, which I think you will agree with me has been very successful. We are going to hold many more of these and it is the aim and object of your local committee to make these as interesting and as comprehensive as possible so that every branch of engineering to which the Institution of Production Engineers applies will be dealt with, and we have many very eminent gentlemen who are coming down here to discuss various subjects and to lecture on subjects which I am sure will be of interest to you all. I should just like you to show your appreciation of Dr. Anderson's lecture and kindness of these two gentlemen, Sir Walter Kent and Mr. Carlton Smith in the usual way.

Dr. Anderson and Sir Walter Kent suitably replied.

INAUGURAL MEETING OF THE EDINBURGH SECTION.

FOLLOWING a Conference at Edinburgh presided over by Sir Walter Kent, C.B.E., President of the Institution, on October 24th, 1934, when it was decided to form an Edinburgh Section, the Inaugural Meeting of the new Section was held at the North British Station Hotel, Edinburgh, on January 16th, 1935, at 7-30 p.m. Mr. James Wright, President of the Glasgow Section, occupied the chair for the first part of the proceedings.

MR. JAMES WRIGHT: I am privileged to-night to welcome you to the Inaugural Meeting of the Edinburgh Section of the Institution of Production Engineers, on behalf of our worthy President, Sir Walter Kent, and I assure you that it gives me great pleasure to preside at such a distinguished gathering. Having already attended your preliminary meeting, I feel that it would be wasting time to enlarge upon the work and scope of the Institution, because I gathered at that meeting that you were already sufficiently well versed in its activities, and so keen in your desire for a local section that all you now need is the active support and enthusiasm of your committee and members to ensure success. You are fortunately situated as an engineering centre, with a variety of products to your credit, and you already have excellent facilities for training and educating the younger members of your profession, coupled with a desire on the part of the principals of your technical college to assist and co-operate with you in your efforts to make this section of the Institution worthy of this great city.

You will no doubt be called upon from time to time to answer the question as to why yet another Institution should encroach upon your leisure time. We in Glasgow have answered that question by transforming our provisional committee of six members in October, 1930, into a healthy membership of almost 90, in spite of the extreme period of depression through which industry has passed since that date.

In building up your section you must bear in mind that progress may be slow, because the qualifications necessary for membership are such that there is not more than one or at the outside two possessed of the executive ability or in a position of independent responsibility in any one firm, who would be accepted by the Council for full membership.

There are, however, various grades into which junior members of your production staff may be placed, and it may be opportune to make special mention of the Graduate examination, which takes

place annually in each centre, where facilities are arranged for the suitable training of potential Graduate members. It is from this source that you lay the foundation for your future success, and I suggest that your committee get to work immediately, with the assistance of the General Secretary, in an effort to solicit the interest of those concerned.

Another matter of interest I would like to mention is the belief in some quarters that the production engineer is only concerned with the actual manufacturing methods of a particular product; this is an entirely wrong construction as will be evidenced by the current syllabus of the Institution. During the present session, for instance, there are 18 papers scheduled to be read dealing with the subject of Industrial Management in its various forms. The terms "scientific management" and "production engineering" are synonymous, and are the outcome of a new technique, which in turn is a desire to extract the maximum amount of saleable goods from a minimum of time, space, labour, and equipment. Some of our overseas competitors have developed this new science to a point where an ailing company may solicit the help of a management engineer in a similar manner to the sick person calling in a medical practitioner.

His business is to diagnose the trouble, eliminate waste, institute correct methods of production control, improve methods of manufacture, introduce a sound wage payment system and study market analysis. This last item can yield astounding results, for it has been found that out of a scientifically conducted investigation there will emerge valuable sales producing territories. Personally, I shall not be content until I see the words "scientific management" incorporated in the title of our Institution. With the more intense competition, there is more and more need for a higher standard of efficiency in our industry, not only locally, but nationally, if we hope to regain our former position as the world's greatest providers.

Conditions may change whereby our former foreign customers will cease to pursue their present insular and nationalistic policy and be content to supply only the raw materials for us to manufacture, in which case we must not be unprepared. Germany, United States of America, and Japan can be relied upon to exploit art and science to the very utmost. We must do likewise.

This Institution makes a definite study of this new technique of which I have spoken, and it matters little whether you are engaged in the manufacture of small interchangeable components and accessories, ships, electric motors, or heavy engine work, there is a common interest which calls for the interchange of ideas, and it is in this direction, gentlemen, that you will find your papers and discussions to be most beneficial.

In conclusion, I want to convey to you the personal message from Sir Walter Kent to the effect that this new section has his very best wishes and, he sincerely trusts, a most successful future. Might I be permitted to couple with that message the congratulations of the whole of the Glasgow committee and membership, and I extend to your president, Mr. Bennet, the offer of any assistance that we may be able to give to further the success which I am satisfied is already assured.

MR. J. RUTHERFORD read messages of congratulation and good wishes from numerous members and officials of other sections of the Institution.

MR. J. BENNET, Section President, was then installed in office and, having taken the chair, introduced Mr. W. G. Groocock, Member of Council, who read a Paper on "The Functions of the Production Engineer."

MR. GROOCOCK, before proceeding to the subject of his lecture, said :

I would like first to express my pleasure at having the opportunity of addressing you on your opening night. I had the same privilege at the Inaugural Meeting of the Glasgow Section, and I distinctly remember prophesying at that meeting that before very long another Section would be needed in this area. As a Member of the Council of the Institution I may be permitted to welcome you to our family. I have also been instructed by the Birmingham Section Committee to convey to you, Sir, a message of goodwill. We at Birmingham, like all the other Sections of our Institution, will do all we can to assist you in making the Edinburgh Section a success. We regard every new Section brought into being as one more stepping stone on the road to progress.

If we were asked to give our opinion on the factors that have had the most influence on human progress during the ages we could not in our answer overlook the importance of lines of communication in this respect. Anything that tends to bring people nearer together is important, and this Institution of ours is designed specifically to provide lines of communication between production engineers in all parts of our country and probably, at a later date, all parts of the world.

Speaking of lines of communication, I recently had the privilege of listening to a lecture on bridges—ancient and modern, and during the lecture I was particularly impressed by the constant stressing on the part of the lecturer that bridges, while they served for many purposes, had two outstanding characteristics ; first, they provide for the intercommunication of people in different territories, and, secondly, and probably more important still, they serve also as the means of communication for trade purposes.

Now each Section of our Institution that has been formed can

be regarded as a bridge on the lines of communication between certain production engineers and others who, prior to the building of the "bridge," had difficulty with their communications. That is, any new Section bridges the gap between a new district and the other production engineers of this country and puts them into close communication. The closer together that production engineers can get, the more free the communication; the better the flow of thoughts; then the better, undoubtedly, it is for trade. That is why I regard every new Section that our Institution brings into being as another bridge on the road to progress.

Last summer I had the opportunity of spending a fortnight's holiday in the Highlands and I saw during my holiday several bridges of note. Some credited to General Wade could not with any stretch of the imagination be said to have been built for trade purposes, but, undoubtedly, they were built to provide lines of communication. I also saw one of the finest examples that was ever conceived and carried out, namely, the Forth Bridge, and in this connection this Bridge does serve both as a means of communication between people and for the purposes of trade.

To-night, by this Inaugural Meeting, you have built another "bridge" in this district which will serve to bridge the gap between production engineers in this area and those belonging to other Sections. I believe the "bridge" of the Edinburgh Section of the Institution of Production Engineers will have a high value in serving that progress which we all so desire. It will allow of free communication between the various production engineers in this country, and, by so doing, will be of great value in its help to trade.